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Evaluation of the Oil Spill Risk Analysis as Presented in St. George Basin Sale 89 EIS

Jones and Stokes Associates, Inc., Bellevue, WA

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This report describes and evaluates the current approach to the oil spill risk analysis as conducted for St. George Basin Sale 89. An oil spill trajectory analysis (OTSA) model was developed for the U.S. Minerals Management Service to calculate the risk of oil spills damaging environmentally sensitive resources. Although the oil spill risk analysis appears to be capable of providing a reasonable and adequate assessment of impacts, its interpretation and use in the EIS should be modified in several key points. The purpose of this report is to review the Minerals Management Service oil spill risk analysis as presented in the Lease Sale 89 EIS.

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Submitted to:

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EXECUTIVE SUMMARY

An EIS must fully disclose the information and analytical procedures used in assessing impacts. The oil spill risk analysis is a key component of EISs prepared for OCS oil and gas lease sales. EPA Region 10 became concerned about the reasonableness and adequacy of the oil spill risk analysis used in EISs for oil and gas lease sales in the Bering Sea. This report describes and evaluates the current approach to the oil spill risk analysis as conducted for St. George Basin Sale 89.

Overview of Approach to Risk Analysis

An oil spill trajectory analysis (OSTA) model was developed for MMS to calculate the risk of oil spills damaging environmentally sensitive resources. The model has three distinct parts. These parts produce a combined probability that one or more large (≥1,000 bbl) oil spills will occur during the life of the field *and* contact a sensitive resource area.

The first part of the OSTA model uses historical spill data from all U. S. OCS areas to estimate the expected number of spills for different types of activities (e.g., platform spills, modes of transportation). The second part of the model predicts trajectories of spilled oil given that a spill occurs at selected points. The third part of the model combines the probability that a spill will occur with the probabilities associated with trajectory simulations. Each launch point is weighted by the volume of oil handled. The total risk to a resource area is the probability that spills will occur at each launch point combined with the probability that those spills will reach the target.

Oil Spill Risks

As might be expected, the oil spill risk evaluations are inherently uncertain. Uncertainty arises from a number of sources: the estimates of mean-case resource levels, the statistics derived from historical spill records, and the scenarios chosen for development of the field. Because the risks are based solely on the mean-case resource estimate, the probability of a spill is derived from a single exposure index tied to production.

The uncertainty in frequency of very large spills (>100,000 bbl) is extremely large because it is based on an extrapolation of statistics outside of the range of observations.

There is no unique way to pose a spill risk model. The approach taken is as reasonable as can be if it is a priori constrained that the risks are to be based on a single exposure index.

Oil Spill Trajectories

The ocean and atmosphere modeling studies used by MMS appear in principle to be capable of generating a reasonable and adequate impact assessment. The ocean model is capable of describing oceanic circulation, and the meteorological model is capable of simulating winds. There remains concern about the way the two models are coupled since the coupling is done at the expense of faithful reproduction of baroclinic currents. However, the potential errors are not considered serious since baroclinic currents are not a major concern with regard to surface dispersion of oil.

The most serious concerns are that the number of trajectories used may be insufficient for adequate projection of risks and that summer conditions may be under-represented in the statistics reproduced in the EIS.

Conclusion and Recommendations

Insufficient information is presented in the EIS and its support documents to evaluate the reasonableness and adequacy of the oil spill risk analysis. Personal communication with the analysts was necessary to obtain important information about some basic features of the risk analysis.

Although the oil spill risk analysis appears to be capable of providing a reasonable and adequate assessment of impacts, its interpretation and use in the EIS should be modified in several key points. The reason for this finding is based primarily on the recognition of great uncertainties in the risk assessment and the subsequent need for a reasonable and adequate worst-case analysis. We recommend that:

- Sufficient trajectories should be run to assess error bounds on their probability distributions.

- Greater consideration should be given to use of conditional probabilities in assessing the environmental consequences of the project.

- The EIS should include a discussion of the impact of season on conditional probabilities, particularly the summer season with reference to the Bering Sea lease sale EISs.

- Little credence should be given to the EIS's summary of overall risk as currently presented.

- The EIS should better document what meteorological and oceanographic features of the environment are incorporated in the trajectory simulation model. A separate document should be published that describes how these features are modeled.

- The EIS should clearly document the assumptions made and their implications when appropriate. In particular, those implications that may ultimately compromise the worst-case analysis must be clearly stated.

Chapter 1

INTRODUCTION

Purpose and Objectives

The Minerals Management Service (MMS) of the U. S. Department of the Interior conducts oil and gas leasing on the U. S. outer continental shelf (OCS). The leasing process is subject to the National Environmental Policy Act (NEPA), which requires that MMS evaluate potential environmental impacts such as an oil spill damaging environmentally sensitive resources. NEPA also requires that the Environmental Impact Statement (EIS) be a full disclosure document, i.e., that the assumptions and analytical methodologies be clearly described in plain language such that decision makers and the public can understand how the findings of fact have been derived from the description of the proposed action and the affected environment (40 CFR Section 1502.1 and Section 1502.8).

EPA Region 10, pursuant to NEPA and Section 309 of the Clean Water Act, reviews draft and final EISs prepared by MMS for proposed oil and gas lease sales. During review of the DEIS (DOI 1984) for Lease Sale 89 (St. George Basin), EPA Region 10 became concerned about the documentation for the oil spill risk analysis and the reasonableness and adequacy of the models used to develop the risk analysis. With respect to biological resources in the affected environment, the oil spill risk analysis is one of the most important features of the impact assessment.

The purpose of this report is to review the MMS oil spill risk analysis as presented in the Lease Sale 89 EIS (DOI 1985) and its supporting documents. The objectives of the report are to:

- Describe the MMS approach to the risk analysis.
- Determine whether the underlying assumptions and structure of the risk analysis are reasonable.
- Provide recommendations to EPA regarding the interpretation and use of the oil spill risk analysis in assessing the environmental consequences of the proposed action and alternatives.

Overview of MMS Model Approach

An oil spill trajectory analysis (OSTA) model was developed for MMS to calculate the risk of oil spills contacting environmentally sensitive resources. The OSTA model is described by Smith et al. (1982). The primary concern in using the OSTA model are spills of 1,000 barrels (bbl) or larger. The 1,000 bbl cutoff was selected to limit evaluations to those spills large enough to travel long distances on the ocean surface and have the potential to do serious damage (Smith et al. 1982; Lanfear and Amstutz 1983).

The model used by MMS has three distinct steps that are taken to calculate probable risk to resources. The first step is common to all oil spill risk analyses prepared for offshore oil and gas lease sales. It calculates the unit risk, i.e., the expected number of oil spills of 1,000 barrels (bbl) or greater per unit volume of oil handled during certain types of activities. As might be expected, there is considerable uncertainty in forecasting whether spills will occur and, if so, how many and how large. Thus, the model uses a probability distribution partially based on historical data from other U. S. OCS lease sales. Spill occurrence rates for different activities were developed by Lanfear and Amstutz (1983) and Nakassis (1982). Spill rates are assumed to be directly proportional to the volume of oil produced and are reported as expected number of spills per billion barrels (Bbbl) produced or handled.

The second part of the model addresses the conditional probability of an oil spill hitting a specified target, i.e., it assumes that a large spill occurred at a specified location. The likely paths or trajectories of an oil spill are also probabilistic because they depend on wind and current conditions during and following the spill. Conditional probabilities reported in the EIS are averaged out for the life of the project, i.e., seasonal variations in trajectories are averaged. Thus, the conditional risk reported in the EIS is likely to be greater or less than the true conditional risk for a given season.

The output from the first and second parts of the model are then used to estimate the combined risk to specified sensitive resource areas. The MMS OSTA model uses matrix algebra (specifically, matrix multiplication) to calculate the combined probability of an oil spill occurring and making contact with a target. One matrix lists the conditional probabilities derived from the trajectory analysis, i.e., each element in the matrix represents the mean probability that target "i" is hit by a spill occurring at point "j". The second matrix represents spill occurrence, i.e., each element in the matrix represents the expected number of spills occurring at "j" as a result of production of a unit volume of oil at site "k". The points "j" and "k" are distinguished because some launch points ("j") represent locations along a pipeline or tanker route.

The resulting product matrix is then multiplied by the volume of oil expected to be found at production site "k" to obtain a final product matrix containing the expected number of oil spills that occur and contact target "i". Thus, each launch point is weighted by the amount of oil handled over the life of the project at that point. Thus, the combined probability is used to determine the overall combined probability, which expresses the risk to a specified target from all the launch points. It is this latter figure (sum of the combined probabilities) that is instrumental in the EIS assessment of impact to environmental resources. The mathematical derivation of combined probability for each launch point is important to understand because this probability is less than the conditional probability unless the volume of oil handled at that launch point is high enough that the expected number of spills is ≥1.

Before examining the details of the oil spill risk analysis, it should be noted that large spills (>1,000 bbl) are assumed by MMS to be rare, random, independent events. The Poisson probability distribution is a mathematical method of describing the probability of such rare events. The Poisson distribution is defined by only one parameter: in this case, the expected number of spills. Thus, the elements in the final product matrix are inserted in the Poisson distribution formula to calculate the probability of one or more spills occurring and hitting a specified target ("i").

Summary of St. George Basin EIS

The following discussion briefly describes the oil spill risk analysis as used (Samuels 1984) for the proposed action described in the St. George Basin EIS. The proposed action calls for pipelines connecting production platforms north of 56°N Latitude with a facility on St. George Island. Oil would then be tankered south through Unimak Pass. Production platforms south of 56°N Latitude would connect to an offshore collection platform where oil would be loaded and tankered south.

Spill Rates for Proposed Action

Unless specified otherwise, spill rates described in this chapter refer to spills ≥1,000 bbl, i.e., those treated in the oil spill risk analysis for the EIS. Spill occurrence rates were calculated separately for the northern and southern sectors of the lease sale with the assumption that the mean case production scenario for the field (1.124 Bbbl) would be equally divided between northern and southern sectors (Hale pers. comm.).

For transportation activities in the northern sector, spill rates of 1.6/Bbbl for pipelines, 0.2/Bbbl for tankers in port, and 0.9/Bbbl for tankers at sea were used. For tankers at sea, MMS assumed that the rate would be 0.45 rather than 0.9/Bbbl because of a 50 percent chance that the spill would not occur in the lease sale area (Hale pers. comm.). Thus, for the northern sector, transportation-related spill rates were assumed to be 2.25/Bbbl (1.6 for pipelines, 0.2 for tankers in port, and 0.45 for tankers at sea), or 1.26 transportation-related spills expected for the northern sector of the lease sale (2.25 x 0.56).

Similar calculations were made for the southern sector; however, spill rates for tankers loading from collection platforms were assumed to be included in spill statistics for tankers at sea (Prentki pers. comm.; DOI 1985, p. IV-7). Thus, for the southern sector, transportation-related spill rates were assumed to be 2.05/Bbbl (1.6 for pipelines and 0.45 for tankers at sea), or 1.15 spills expected (2.05 x 0.56).

Platform spills ≥1,000 bbl were assumed to occur at a rate of 1.0/Bbbl, i.e., 1.12 spills for the entire lease sale. Thus, for the St. George Basin lease sale, 3.54 spills are expected (2.42 for all transportation plus 1.12 for platforms) for the proposed action. Using the MMS-assumed probability distribution (the Poisson distribution), the expected number of spills yields a probability of 0.97 that there will be one or more spills of ≥1,000 bbl.

Oil Spill Trajectories

In Atlantic, Gulf of Mexico, and California OCS lease sale EISs, MMS used the full OSTA model to predict oil spill trajectories. Wind and current data were used and applied to as many as 100 launch points and 500 hypothetical spills from each launch point for each season of the year.

In Bering and Beaufort Sea lease sale EISs, a numerical model developed by the Rand Corporation (Liu and Leendertse 1982) was used to predict trajectories. Oil spill trajectories were generated from 29 launch points within the lease sale boundary with 26 trajectories each during ice-free conditions and 36 trajectories each for winter conditions of average ice cover. The trajectories were used by MMS with the OSTA model to evaluate the probability of risk to targeted resources.

Overall (Combined) Spill Risk Probability

The volume of oil assumed at each launch point is critical to the calculation of the combined probability. In the case of Sale 89, the lease sale area can be divided into subregions based on the resource estimates. The Pribilof Island and Unimak Pass deferral areas are assumed to contain 10 and 5 percent of the total resource, respectively. The remaining subregions of the northern and southern sectors contain 40 and 45 percent of the resource, respectively. Within each subregion, the expected production is divided equally between the launch points (Hale pers. comm.).

For transportation-related spills, the expected number of spills associated with the volume produced at "k" is divided equally among the launch points carrying that volume. The expected number of spills at a particular launch point is the sum of these allocated fractions. This sum is then multiplied by the volume of oil produced at "k" to give the weighted spill risk. Thus, the spill is geometrically accumulative as oil moves through a collection system to a storage or processing area. However, the allocation and weighting procedure does not result in "multiple counting" of the transported volumes for that particular mode of transportation. In other words, the expected number of transportation-related spills for a particular transportation mode in the lease sale does not exceed the unit risk for that mode of transportation multiplied by the mean-case production estimate for the field. "Multiple counting" occurs only in the sense that the same barrel of oil may be collected and transported by pipeline and then shipped by tanker out of a storage facility and, therefore, that oil is exposed to two separate transportation-related risk calculations.

Cumulative Spill Risk

As part of its evaluation, MMS includes an analysis of oil spill risk from the cumulative activities in the Bering Sea, i.e., other Bering Sea lease sales and transportation of oil from Arctic production fields. In developing the cumulative-case scenario for the DEIS, MMS assumed that the proposed action for Sale 89 will be replaced by the pipeline transportation alternative because the North Aleutian Basin lease sale (Sale 92) involves pipeline activity adjacent to St. George Lease Sale 89, and it would be more reasonable to tie the southern sector of Sale 89 to the Sale 92 pipeline system (Hale pers. comm.). Expected number of spills in the cumulative case (DOI 1984, Table IV-9) is calculated from the sum of the operations (DOI 1984, Table IV-5) and used in the Poisson distribution formula. In the FEIS, MMS assumed that the proposed action for Sale 89 would also be valid for the cumulative case, and the expected number of spills (DOI 1985, Table IV-10) is readily obtained from data in Table IV-5 of the FEIS.

Chapter 2

OIL SPILL RISKS

Summary

MMS uses a log-normal distribution to estimate the probability distribution for sizes of spills. The agreement between calculated and observed frequencies of spill volume appears reasonable. Although the approach provides the best estimate that can be made, it should be noted that the approach can result in extremely large uncertainties.

Similar conclusions are made for the frequency of large spills. MMS assumes large spills occur as a Poisson process and that the expected number of spills can be derived from past OCS history and the mean-case resource estimate for the proposed field. The approach taken by MMS is reasonable, but the expected number of spills that is derived by the approach is characterized by great uncertainty. An important element of the risk analysis is the selection of the exposure index used to develop the mean expected number of spills. The assumptions made about the exposure index are not demonstrably better than alternative assumptions, and alternative assumptions very likely would alter the expected number of spills. However, the degree of uncertainty at all steps in the calculations is so large that only great changes in the expected number of spills are likely to have any real meaning.

The large uncertainty inherent in the calculation of expected number of spills is of greater significance to the impact assessment than small modifications of the calculated number.

General Discussion

Risk assessments are generally probabilistic in nature. Three fundamental elements in a risk assessment model are: 1) the probability distribution function, which provides the probabilities of events; 2) an exposure index, which sets the probability parameters; and 3) the ability to predict future events using the exposure indices. A sufficient number of historical events, each with the same exposure index, allows evaluation of the probability function. With a small database, however, assumptions on the nature of the probability function must be made. These assumptions are not verifiable in an absolute sense and can only be judged by their reasonableness.

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To determine the exposure index requires first that the distribution function is known and then that it is known for a number of different exposures. Exposure indices that are good fits to the data but not predictable into the future are of little value. If the exposure index is not predictable, then forecasting is not possible.

The MMS oil spill risk analysis model must be considered within the constraints mentioned above. Because vastly different inferences can be drawn from similar data, the burden of proof is always on the declarer to present a thorough description of the steps leading to conclusions.

Data on spill incidents are kept by a number of sources: the U. S. Coast Guard, the U. S. Geological Survey, EPA, and Lloyds of London. The recent compilation of data for the DOI by The Futures Group (1982) represents the most complete set of publically available information. The Futures Group report classifies spills by five sources: platforms, pipelines, single buoy moorings, tankers at sea, and tankers in ports. These categories, where possible, are further subdivided by cause of spill. The Futures Group, however, was not able to complete the analysis of appropriate exposure indices; therefore, their conclusions are tentative and expressed as suggestions for further study.

The technique adopted by MMS to highlight the disproportionate importance of the rare, large spill is to analyze the problem in terms of spill frequency models and spill volume distributions. The former are used to predict the number of spills that might occur, the latter to predict the volume spilled given the event. The predictions are made in terms of probabilities, i.e., "n" spills will occur with the probability P(n) and less than "x" gallons will be spilled with probability P(x).

Size of Spill

MMS selects spills of volume $\geq$1,000 bbl for its risk analysis model based on the belief that portions of spills of this size or larger remain on the water surface long enough (30 days) to be transported away from the source to environmentally sensitive areas (Lanfear and Amstutz 1983). These authors also point out that a 1,000 bbl spill is large enough not to go unnoticed, so reporting records tend to be reliable.

A 10,000 bbl spill is likely to have the same environmental impact as a 12,000 bbl spill. Thus, in terms of risk analysis, the size of a spill need not be defined to great precision. In the oil spill risk analysis, therefore, the primary effort is devoted to frequencies of spillage. The frequency distribution for spill volumes is of interest, however, from the standpoint of worst-case risk analyses. MMS assumes that spill volumes

≥100,000 bbl constitute a worst-case; smaller spills are more frequent but also tend to be more localized in their adverse effect. To determine the probability of an event requires a great deal of data. It is impossible to determine with a small data set the correctness of any of the distribution functions chosen. Unfortunately for the statistician, there have been too few spills of ≥100,000 bbl for proper study. Thus, a means is needed to estimate the probability of these events.

Lanfear and Amstutz (1983) compare the distribution of spill sizes (spills ≥1,000 bbl) for both platform and pipeline spills with a log-normal distribution. The agreement is reasonable and the log-normal distribution is probably the best assumption that can be made. It should be noted that the log-normal distribution is a generic distribution used to fit widely scattered data. Deriving rates for this distribution, particularly outside of the range of data used to evaluate the distribution, can result in extremely large uncertainties.

In the FEIS for Lease Sale 89 (DOI 1985), spills of ≥1,000 bbl and ≥100,000 bbl were considered. Because there have been no platform spills of ≥100,000 bbl, the log-normal distribution function was used to evaluate the probability of platform spills ≥100,000 bbl. The extrapolated rate constant is 0.036/Bbbl. Of eight pipeline spills in the OCS records, one was >100,000 bbl. Using the same distribution function as for platform spills, MMS evaluated a spill rate of 0.065/Bbbl for pipeline spills ≥100,000 bbl (DOI 1985, p. IV-7).

Approach to Estimating Spill Frequency

The following critical assumptions about spill frequency are used by MMS in its risk analysis:

- Future spill frequencies can be based on past OCS experience (DOI 1985, p. IV-6).
- Spills occur independently of each other (DOI 1985, p. IV-6).
- The spill rate is dependent on the volume of oil produced or transported (DOI 1985, p. IV-6).
- The mean-case estimate of the oil resource can be used to estimate the volume of oil produced (DOI 1985, p. IV-6).

The reasons for and implications of these assumptions are useful in interpreting the reasonableness of the oil spill risk analysis.

The Applicability of Past Experience

It would be unreasonable to presume that the physical environment (or working conditions) of the harsh, stormy Bering Sea is comparable to existing U. S. OCS conditions (i.e., the Gulf of Mexico and southern California). Even Cook Inlet does not experience the storm and wave conditions typically found in the Bering Sea.

It is reasonable, however, to presume that production platforms will be engineered to meet the environmental rigors of the lease sale area. This implies a second assumption, i.e., that the engineering of platforms has met the environmental rigors of existing oil fields. The implied assumption has not been strictly satisfied, but improvements have been made in technology as a result of previous accidents. Since oil recovery technology is not starting from a new basis in each new development, it is permissible to take into account trends in reduction of spill rates in the risk evaluation. MMS currently evaluates risk based on a model (Nakassis 1982) which maintains the critical assumptions in the risk analysis but allows for industry improvement. Analysis shows that platforms and tankers have shown improvements in spill rates over time; pipelines have not.

Independent Events

A basic assumption of the approach taken by MMS is that spills occur as a Poisson process, with volume of oil produced or handled as the exposure variable. One of the key supporting documents for the MMS oil spill risk analysis is the Nakassis (1982) study of platform spills, discussed in detail in Appendix A. Nakassis was unable to conclude that large oil spills occur as a Poisson process, but he assumed a Poisson process in order to test the hypothesis that platform spill rates have decreased over time. Subsequent work (Lanfear and Amstutz 1983) continues to assume large oil spills occur as a Poisson process.

One way of understanding the Poisson distribution is to understand how it may be derived from games of chance. The outcome of such games is a win or lose situation with a probability of winning or losing. How does one fare after "n" trials in a game with a probability "p" of winning and a probability "q" of losing? The answer is given by the binomial distribution function, but this function is complicated. If the gambler seldom wins and wins are random and independent events, success is approximated by a Poisson process, which is a considerably simpler mathematical expression to deal with. In a number of problems, rare and random events are counted and the average rate (expected value) of some process is thereby estimated using the hypothesis that they are Poisson distributed.

Oil spills are approximated by this Poisson distribution on the assumption that they are rare events. Several oil spills in the Gulf of Mexico occurred in October 1964 as a result of a single hurricane. Consistent with the Poisson assumption, MMS treats these as one event. In accident work, the fact that people are more careful after a series of accidents causes deviations from the Poisson law. MMS modifies the Poisson law parameters to include industry improvement in its rate predictions (Nakassis 1982).

Table 2-1 shows how well the mean expected value of a Poisson process is estimated as a function of the number of observed events. The table illustrates the difficulty of estimating a true mean even if it is known that the information comes from a Poisson process. Verifying that a process is Poisson would be even more difficult.

Occasionally it will be possible to test directly the Poisson assumption in its entirety. If there are numerous observations, each with the same exposure, then the associated numbers of spills represent independent observations from a single Poisson distribution, and the standard statistical tests for goodness-of-fit can be employed. A possible case is tanker spills, where a contemplated exposure index is tanker-years. Every tanker which has been in service for the same period will have the same exposure. Stewart and Kennedy (1978, p. 24) performed goodness-of-fit tests in this situation and concluded the Poisson model was acceptable.

Spill Rates and Volume of Production

A risk assessment model cannot be formulated without an exposure index. Criteria for choosing an exposure index (Smith et al. 1982) are:

- It should be simple.
- It should not intuitively violate to any significant extent technical assumptions made in the analysis (this refers primarily to the Poisson assumption).
- It should be a quantity that is predictable in the future.

MMS has chosen to characterize the risk associated with production of oil from a lease sale area with a single number: the expected number of spills of $\geq$1,000 bbl during the life of the field. This number is related to experience by the assumption that the number of spills is proportional to the total expected production from the oil field. Thus, if the anticipated production is a tenth of the production of the "past experience production," then the risk is a tenth of that in the "past experience data."

The approach scales all risks according to anticipated volume of production. This is a simplification of oil recovery operations that avoids consideration of the many factors that

Table 2-1. Confidence Intervals for the Expected Value of the Poisson Distribution

	LEVEL OF CONFIDENCE			
	90%		98%	
OBSERVED COUNT	LOWER LIMIT	UPPER LIMIT	LOWER LIMIT	UPPER LIMIT
0	0.0	3.0	0.0	4.61
2	0.355	6.3	0.149	8.41
4	1.37	9.15	0.823	11.60
6	2.61	11.84	1.79	14.57
8	3.98	14.43	2.91	17.40
10	5.43	16.96	4.13	20.14
20	13.25	29.06	11.08	33.10

SOURCE: Wilson 1952

bear on possible causes of spills. There is some justification for this approach. At the time of leasing, it is not known if oil will be discovered and, if so, where in the lease sale area the oil would be found. Because the risk statistics are based on interpretation of past experience independent of causal factors, scenarios depicting the number of wells, tanker traffic, or lengths of pipelines are used only to allocate share of the total risk. A consequence of this choice of exposure index is the important assertion that all activities involved in the production of oil over the lifetime of the field are directly related to total production. Thus, even spills associated with transportation of oil are directly related to volume of oil produced.

It may not be practical to find an alternative exposure index to total production. It can never be known if oil is present in commercially marketable quantities until a discovery has been found by drilling. It is also reasonable to assume that environmental regulation and environmental awareness of the industry will result in technology meeting the environmental rigors. However, adoption of the above assumptions precludes the inclusion into the risk analysis those factors which individually constitute real elements in the risk. Such factors are:

- rapid changes in production as a result of world oil demand, which might result in the use of developing technology;
- production with a few very large platforms rather than many smaller platforms;
- rapid or slow development based on economic conditions of the industry;
- large local tank storage because the marine climate shortens "windows" during which tankers can be safely loaded;
- tectonics of the region;
- use of the lease area in activities other than oil production, e.g., fishing in the Bering Sea;
- comparison of alternate modes of oil transportation in terms of net risk; and
- important variations in transportation modes, e.g., long and large pipelines instead of many short and small pipelines, and/or the use of a few large tankers instead of many small tankers.

Mean Case Estimates

Anticipated resource levels and volume of production during the lifetime of an oil field are derived from geological information and information from neighboring regions. It is difficult to place a strict confidence limit on this number. The resource estimates are based on primary production methods, thus volume of production and the expected number of spills are also based on primary production methods. Limitation of the oil spill risk analysis to primary production is perhaps reasonable since it is not certain that oil will be found let alone whether secondary production is economically practical. It is important, however, to recognize that this limitation may have a bearing on the interpretation of the mean case and maximum case resource estimates and production life of the field.

Reasonableness of the Approach

It is clear from the foregoing discussion of the assumptions of the spill risk analysis that estimations of expected number of spills are characterized by great uncertainty. The degree of confidence in the calculated expected number of spills decreases as one examines in detail its derivation. This is not to say that the approach is unreasonable, rather it means that unquestioning acceptance of the expected number of spills at face value is unreasonable. The approach is reasonable to the extent that the calculated values can be used to determine whether the probability of a spill is relatively high or low. Thus, the great deal of effort expended in refining the expected number of spills (even by as much as a factor of two or so) may not be warranted in view of the large confidence interval inherent in the Poisson statistics (Table 2-1).

MMS-Assumed Frequencies of Oil Spills

The MMS OSTA model uses risk estimates for different operations in offshore oil production. There are two main categories: platform and transportation spills. Included in platform spills are blowout, tank, and miscellaneous spill categories. Included in transportation are pipelines and tankers at sea and in port. The spill rates are derived from historical data using assumptions about the industry. In all cases discussed below, only spills $\geq$1,000 bbl are considered unless otherwise noted. The number of spills this large in the historical record is not uniformly agreed upon by the various analysts who have used the spill records.

Platforms

Before 1981, OSTA model runs used OCS platform spill rates based on studies by Devanney and Stewart (1974) and Stewart (1975). The database for this work was 10 spills of $\geq$1,000 bbl in handling 5.338 Bbbl, yielding a rate of 1.87 spills/Bbbl.

Samuels et al. (1981) used U. S. Geological Survey (USGS) accident records (1979a, 1979b), which reported nine spills of ≥1,000 bbl from 1964-1979, and used a 1964-1980 federal OCS oil production of 4.386 Bbbl to compute a rate of 2.05 spills/Bbbl of oil produced.

Nakassis (1982) examined the spill record and concluded that a trend existed that indicated improvement in the platform spill rate (Appendix A). Using a maximum-likelihood approach, he estimated that the present spill rate for U. S. OCS platforms is 0.79 spills/Bbbl. Nakassis began with the assumption that spills can be represented by a Poisson process. He did not prove that oil spills come from a Poisson process (Appendix A).

To help update its own estimates of spill rates, DOI contracted with The Futures Group to prepare a database of oil spills and to perform a preliminary analysis of spill rates. Completed in September 1982, the database contains detailed records of platform, pipeline, and tanker spills. The Futures Group database contains records of 462 platform accidents worldwide from 1955-1980, including 15 spills of ≥1,000 bbl in U. S. waters.

Lanfear and Amstutz (1983) used Nakassis' methodology on the database in Table 2-2 (i.e., excluding three spills that were included by The Futures Group: two spills in 1964 [2,559 bbl and 6,387 bbl] and one spill in 1969 [18,363 bbl]) and computed a spill rate of 1.0 spills/Bbbl of production. This is the figure used in the EIS for the St. George Basin lease sale. Lanfear and Amstutz (1983) modified The Futures Group data somewhat for their analysis. There were several spills in October 1964 that occurred during a single hurricane. Since these spills occurred as a result of the same event, Lanfear and Amstutz chose to make these spills a single event because, if spills are not independent events, they will not be modeled by a Poisson process. Because these spills came early in the study period (1964-1980), the analysis would have indicated greater industry improvement had they not been grouped together. Thus, the analysis is conservative in the way it treated this information.

Pipelines

Most U. S. OCS oil produced is transported via pipelines. The MMS database for U. S. OCS pipeline spills is in Table 2-3.

Because anchor dragging is the prime cause of large pipeline spills (The Futures Group 1982), there is reason to expect that pipeline length is the important indicator of risk. The Futures Group tentatively concluded that pipeline length was a more accurate predictor of failure rate than volume transported. The Futures Group considered all failures regardless of spill size: a total of 235 accidents and a mean spill size of 190 bbl. The Futures Group concluded that corrosion-related failures were on the increase; however, most corrosion-related failures result in small spills.

Table 2-2. Platform Spills (>1,000 bbl) in U. S. Waters, 1955-1980

DATE	LOCATION	SIZE (bbl)	CAUSE
4/8/64	Eugene Island 208	5,108	Collision
10/3/64	(7 Platforms)	17,500	Hurricane
7/19/65	Ship Shoal 29	1,688	Blowout
1/28/69	Santa Barbara	77,000+	Blowout
3/16/69	Ship Shoal 72	2,500	Blowout (weather)
8/17/69	Main Pass 41	16,000	Tank Spill (weather)
2/10/70	Main Pass 41	30,500	Blowout
12/1/70	South Timbalier 26	53,000	Blowout
7/20/72	(Unspecified, Gulf of Mexico)	4,300	Unspecified
1/9/73	West Delta 79	9,935	Tank Spill
11/23/79	Main Pass 51	1,500	Tank Spill
11/17/80	Galveston	1,500	Tank Spill

+ = Estimates vary.

SOURCE: Lanfear and Amstutz 1983.

Table 2-3. Pipeline Spills (>1,000 bbl) in U. S. Waters

DATE	LOCATION	SIZE	CAUSE
10/17/67	West Delta 73	160,638	Anchor Dragging
3/12/68	South Timbalier 131	6,000	Anchor Dragging
2/11/69	Main Pass 299	7,532	Anchor Dragging
5/12/73	Grand Island 73	5,000	Corrosion
4/18/74	Eugene Island 317	19,833	Anchor Dragging
9/11/74	Main Pass 73	3,500	Environmental
12/18/76	Eugene Island 297	4,000	"Damaged"
7/17/78	Eugene Island 215	1,000	Anchor Dragging

SOURCE: Lanfear and Amstutz 1983.

Samuels et al. (1981), using USGS accident data from 1964 to 1979, computed a rate of 1.82 spills/Bbbl produced for spills of ≥1,000 bbl. For large spills (≥1,000 bbl), Lanfear and Amstutz (1983) stated, "On a likelihood basis, volume of oil is better than km-yr in explaining the spill record. The length of pipelines has increased more than threefold since 1969, with no corresponding increase in spill occurrences. Perhaps km-yr, adjusted for some experience factor, may yet prove to be a superior exposure variable. However, such an adjustment would cost a statistical analysis at least two degrees of freedom (for shape and parameter value), making its superiority very difficult to demonstrate with only eight spill occurrences." On the basis of data through 1980, Lanfear and Amstutz suggested that the expected spill rate should be 1.6 spills/Bbbl produced.

Tankers

Tankers present a problem in assigning risks. The difficulties of finding exposure indices for tankers are considerable. For example, 1983 had the lowest rate of tanker accidents in 16 years. The world tanker fleet shrank in 1983, and more restrictive operating rules were in effect for this year; nevertheless, recent figures in the 1983 Oil Spill Intelligence Report (New York Times, Oct. 7, 1984, p. 34) show a 930 percent increase in spill volume in 1983 vs. 1982. Approximately 241.8 million gal of oil were lost by spillage, fire, or sinking in 1983. This is the largest amount of oil lost since 1979. Of the total, 80 million gal were associated with the Middle East conflict and an additional 78.5 million gal were lost when a tanker burned and sank near South Africa.

The DOI did not maintain a database of tanker accidents as it did for platforms and pipelines. All tanker spill rates were derived from published world-wide spill data. Devanney and Stewart (1974), examining spills on major trade routes, reported 99 spills of ≥1,000 bbl in transporting 29.326 Bbbl of oil. Stewart (1976) reported 178 spills in transporting 45.941 Bbbl of oil, for a rate of 3.87 spills/Bbbl; all of these spills occurred before 1976.

The Futures Group (1982) database provided the DOI with the first opportunity since 1976 to review and update the tanker spill rates. Because of the difficulty and expense of collecting spill data, primary emphasis was placed on collecting data on spills of ≥1,000 bbl since 1974, although spills of all dates and sizes were included. The data summarized in Table 2-4 contain 855 records of accidents involving vessels engaged in transporting oil as a product.

Spills of crude oil of ≥1,000 bbl, from tankers worldwide are shown in Table 2-5. That at least 31 percent of the spills occurred in harbors or at piers is particularly important for evaluating environmental impacts, as these spills would not be subject to the same advective and weathering effects of winds and currents as spills in open water on the OCS. Earlier analyses

Table 2-4. Summary of Data on Oil Spills from Vessels Carrying Petroleum as a Cargo

YEAR	NUMBER OF SPILLS ANY SIZE	 >1,000 bbl
Pre-1969	49	33
1969	20	13
1970	40	22
1971	47	19
1972	89	44
1973	78	49
1974	82	30
1975	67	27
1976	57	26
1977	88	34
1978	81	27
1979	111	43
1980	76	27
TOTAL	885	394

SOURCE: Lanfear and Amstutz 1983.

Table 2-5. Crude Oil Spills of ≥1,000 bbl from Tankers Worldwide, by Location

YEAR	AT SEA	IN PORT	UNSPECIFIED	TOTALS
1974	10	8	2	20
1975	9	4	3	16
1976	16	4	1	21
1977	12	4	0	16
1978	8	1	2	11
1979	11	9	1	21
1980	3	5	1	9
TOTAL	69	35	10	114

SOURCE: Lanfear and Amstutz 1983.

did not make this important distinction. The Futures Group could not find a statistically significant exposure index. The MMS analysis relies on the Lanfear and Amstutz (1983) paper on spills ≥1,000 bbl. Using an exposure of approximately 88 Bbbl of oil transported between 1974 and 1980, the calculated spill rate becomes 0.90 spills/Bbbl for spills at sea (open, restricted, or unknown waters) and 0.40 spills/Bbbl for spills in port (harbors and piers), for a total of 1.3 spills/Bbbl. Spills in port must be assumed to be divided evenly between the inbound and outbound portions of the voyage, as the database does not make this distinction.

The tanker spill rate since 1974 appears to be only a third of that before 1973. Stewart (1976) reports more spills before 1976 than are contained in The Futures Group database, but this could be due to the latter group's incomplete collection of data from the earlier years (emphasis was on years 1974 and later). Goldberg et al. (1981) also report more incidents for the years before 1972 than does The Futures Group but about the same number for later years. (Their classification scheme, however, is not exactly the same; individual records are not available, so the comparison is only approximate.) Unless the databases are very much in error, it appears that the tanker spill rate for spills of ≥1,000 bbl dropped significantly sometime between 1972 and 1974.

Single Buoy Moorings

The St. George Basin Sale 89 FEIS (DOI 1985) assumes that the risk for single buoy moorings is included in the risk for tankers at sea. The Futures Group considered it a separate category. There have not been any spills of ≥1000 bbl associated with single buoy moorings.

The Futures Group noted a significant increase (above port-related spills) in spill volume associated with loading at single buoy moorings, although the spill rates were about the same as for ports. Ship calls were deemed the best exposure index. Spill rates were three times larger at unloading than at loading; however, volumes lost during unloading were considerably smaller than during loading.

Summary

The unit risk values used by MMS in the oil spill risk analysis are summarized in Table 2-6.

Verification of Spill Risk Estimates

One of the major objectives of this study has been to determine whether the oil spill risk analysis is reasonable and adequate for impact assessment. Two possible ways of achieving this are: 1) testing the projected values against the experience record for a comparable oil field, or 2) examining the effects of

Table 2-6. MMS-Calculated Expected Number of Spills per Billion Barrels

	≥1,000 bbl	≥100,000 bbl
Platforms	1.0	0.036
Pipelines	1.6	0.065
Tankers		
At Sea	0.9	0.190
Per Port Call	0.2	0.042

SOURCE: DOI 1985

alternative sets of assumptions or exposure indices on the projected values.

The FEIS for Sale 89 (DOI 1985) compares the Alaskan spill record with the expected number of spills generated by the oil spill risk analysis. Oil production began in Cook Inlet in 1964. By 1980 about 0.7 Bbbl of oil had been produced. Spill statistics for 1965-1980 are shown in Table 2-7. In Cook Inlet, there were 3 years with total spillage in excess of 1,000 bbl: 1966, 1967, and 1968. These spill volumes resulted from 9 spills in 1966, 9 spills in 1967, and 32 spills in 1968 (DOI 1984). Included in data for these 3 high-spill years were two tanker spills of >1,000 bbl and one pipeline spill of >1,000 bbl. These numbers correspond to pipeline spill rates of 1.42/Bbbl and total transportation spill rates of 2.84/Bbbl if the data are not adjusted for industry improvements.

The following paragraphs are quoted from the Lease Sale 89 FEIS (DOI 1985, p. IV-8). The projected values in the quoted material apparently have been adjusted for improvement in spill rates.

"Because OCS statistics are compiled as 'number of spills per volume produced,' the only comparisons of OCS statistics with Alaskan data are for the state-leased offshore Cook Inlet and Prudhoe Bay/Kuparuk fields. Based on OCS spill statistics, and assuming that Alaska also experienced the post-1974 improvement in platform and tanker (not pipeline) performance seen in OCS statistics, the number of spills which would be projected for the Cook Inlet and Prudhoe Bay/Kuparuk fields are shown below:

Number of 1,000-Barrel or Greater Spills
(through August 1983)

	Cook Inlet		Prudhoe Bay/Kuparuk	
	Projected	Observed	Projected	Observed
Platforms	1.79	0	3.0	1- 3(*)
Pipelines	1.28	2(**)	4.8	6
Tankers	2.06	2	3.9	1
Total	5.13	4	11.7	10

(*) The 3 includes two airfield spills.
(**) From Gulf Research and Development Company 1982.

[Note: The information cited at this point in the FEIS includes spill statistics through 1983. Table 2-7, also from the FEIS, includes data only through 1980.]

SOURCE: MMS, Alaska OCS Region, 1984.

Table 2-7. Cook Inlet Spill Data

YEAR	PRODUCTION (Mbbl)	SPILLAGE[a] (bbl)	NO. OF SPILLS[a]
1965	0.03	87	1
1966	2.65	2467	9
1967	15.9	1982	9
1968	52.5	2278	32
1969	60.9	246	12
1970	70.1	28	9
1971	66.2	75	10
1972	63.7	22	11
1973	61.7	131	12
1974	59.9	150	25
1975	60.0	23	13
1976	54.5	76	15
1977	49.8	10	12
1978	45.0	14	9
1979	38.4	4	5
1980	32.3	3	3

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[a] Spills of known volume.

SOURCE: DOI 1984

"For Cook Inlet, the probability (0) of observing platform spills is 17 percent. The above calculations indicate that we would have projected 5.1 spills to occur as a result of production and transportation of oil in Cook Inlet. In fact, 4 spills were observed. The probability of observing only 0 to 4 spills overall is 42 percent, almost an even chance. Thus, the OCS oil-spill-occurrence statistics applied to Cook Inlet production shows a reasonable agreement with the observed number of spills.

"The OCS statistics project 11.7 spills for Prudhoe Bay/Kuparuk production and transportation; we observed 10. OCS statistics projected 3 platform spills, and 1 to 3 spills (depending upon inclusion of airfield spills) were observed. We projected 4.8 pipeline spills; we observed 6. We projected 3.9 tanker spills; we observed 1. The probability of observing 0 to 1 platform spills is 20 percent, and the probability of observing 1 to 3 platform spills is 60 percent. The probability of observing 5 to 7 pipeline spills is 41 percent. The probability of observing 0 to 2 tanker spills is 25 percent. The probability of observing 0 to 10 spills overall is 38 percent.

"In conclusion, Alaska has not produced enough oil to statistically demonstrate that it has a different spill rate than the rest of the OCS."

The comparison between OCS statistics and the Prudhoe Bay/Kuparuk fields illustrates one of the difficulties in extrapolating data. Of eight pipeline spills ($\geq$1,000 bbl) in the Gulf of Mexico, five were the result of anchor dragging. Anchor dragging is not a significant problem for the trans-Alaska Prudhoe Bay/Kuparuk pipelines. Since anchor dragging is not a possible cause of pipeline spills in the Prudhoe Bay/Kuparuk fields, it is misleading to use OCS statistics as was done above. If the projected pipeline spill rate is adjusted downwards by 5/8, then 1.8 spills would have been predicted instead of 4.8 as listed in the FEIS. This would suggest that the observed pipeline spill rate is much more than the projected rate. However, even this manipulation is challengeable because the Prudhoe Bay and Kuparuk fields are not offshore environments.

Cook Inlet, although a harsh environment for ice and tides, is not an open ocean environment. It does not have the same risk of high wave conditions as the Bering Sea OCS nor does it have the shipping and fishing traffic of the Gulf of Mexico. Apart from these two important differences, use of Cook Inlet data would be reasonable as a rough approximation of the adequacy of the projected values.

Given these considerations, use of Alaskan data to test the applicability of U. S. OCS data should be done with care.

Alternative Approaches

Apart from using different models for U. S. OCS production (e.g., the recent North Sea spill record), probably the only alternative approach to the current oil spill risk analysis is to re-examine the selection of exposure indices. As noted earlier in this chapter, this would entail a more critical examination of the causes of oil spills and less emphasis on the volume of oil produced. The way to achieve this is to identify historical data with regard to cause, i.e., to determine if engineering improvements have lessened the probabilities of certain types of accidents, to determine relationships between certain types of accidents and the environment, and to relate these findings to developments in the proposed lease area. Accomplishing this analysis might require use of the data for spills of all sizes, although the final focus of the subsequent impact assessment would be only on the larger spills. Appendix B has been prepared for the purpose of allowing the reader to visually examine the spill record and relate spill data to different factors.

The primary difficulty with applying a single concept to a risk analysis situation is that confidence limits cannot be derived. One way to achieve a measure of confidence is to consider different models based on different assumptions and then compare risks. If alternative approaches have no major effects on the expected number of spills, then it can be concluded that the spill risk estimates are reasonably accurate. This section is prepared as a preliminary effort to recommend different models or approaches. It is not presented to prove or disprove a risk model.

The North Sea: A High Latitude Oil Field Model

The North Sea oilfield is particularly attractive as an alternative model because the marine environment is similarly harsh, and it is a new production field that underwent rapid development. Use of the model assumes that industry technology and practices are not likely to be significantly different from U. S. OCS practices. Unfortunately, the data were not available for this review. The Futures Group obtained 3 years of North Sea data, which proved to be insufficient for analysis. The main deterrent for further examination of North Sea data appears to be its high cost from Lloyds (Prentki pers. comm.).

Alternative Exposure Indices

One could also develop models that use more than one exposure index as the predictor of spill frequency. This approach would allow for more flexibility in defining senarios for oil field development. The following is a brief list of the types of variables that may be important in determining the exposure index.

Production. This could be further refined to define the number and types of tankers, production platforms, and pipelines.

Changes in Production. This could be an important factor in determining risk, particularly in a region where rapid changes in production are anticipated. Spill data have been graphically related to rate of change in Appendix B. These figures suggest rate of change may have some influence on spill rate, but the necessary statistical evaluation has not yet been done.

Size of Platforms. The database has not been examined for the relative safety records of small vs. large platforms.

Seasons. Risks to mammals, birds, crabs, and migrating fish may have a seasonal dependence. Smith et al. (1982) state that such factors can be put into the MMS model using trajectory data. It may be worthwhile to examine effects of season on spill frequency.

Infrequent Severe Storms. No analysis has yet been done to ascertain the influence of severe storms. If platforms are designed for 50-year storms, what is the probability of the 100-year storm striking during the lifetime of the oil field?

Geological Features. Oil production in highly fractured areas is more hazardous than in more stable areas.

Size of Holding Tanks. The risk of a large spill could increase with increases in average container size.

Size and Frequency of Tanker Traffic. Spills of all sizes from U. S. flag tankers have been shown (Stewart and Kennedy 1978) to occur at a rate of about one per 3 tanker-years. Thus, an alternative exposure index could be compared with the current values in the oil spill risk analysis.

Pipelines. Here there are variables such as length, size, ability to quickly detect and respond to problems, and frequency of anchoring along the pipeline route.

Other Activities. The interactions between other activities (e.g., a large commercial fishery) and oil production activities could change risk estimates. In some cases, these may be closely linked to season.

Incorporating an alternative or even a multivariate exposure index into a risk model would require changes to the present risk analysis and investigation into a number of scenarios. The assumptions operating under the current approach are not demonstrably more reasonable than the alternatives. However, the outcome of such analyses may serve no purpose other than to provide analysts with better information on the causes of spills. The inherent nature of probability functions means that uncertainty will occur about the expected number of spills irrespective of which assumptions are used. It is doubtful that the use of a more accurate exposure variate, for example, will result in greater confidence in the expected number of spills because the confidence interval is so large.

Implications for Impact Assessment

The foregoing discussion indicates that spill risk predictions may be sensitive to different sets of assumptions used to calculate the risk and that there is no compelling reason for accepting any particular set of assumptions over another. The use of a "superior" exposure index may change the expected mean number of spills which, in turn, may significantly alter the probability function. However, decision makers and the public should recognize that the inherent uncertainties in the process are such that changes of this scale are unlikely to substantively reduce the uncertainty. What is more important is recognition of how the uncertainty might affect interpretation of the impact assessment.

Marine birds and mammals are perhaps most susceptible to the effects of oil spills because these animals have frequent and regular exposure to the water surface. Table 2-8 summarizes findings of the impact assessment on these organisms as reported in the FEIS (DOI 1985) or readily derived from the assessment. The four whale species included in Table 2-8 have been selected because they are known to occur regularly and in significant numbers in the St. George lease sale (Jones & Stokes Associates 1984), and they are designated as endangered species. Other endangered cetaceans are either not likely to occur or are so few in number that the probability of contact with an oil spill is particularly remote.

The table shows the MMS-calculated combined probability that a spill will occur and contact the Pribilof Islands area, the Unimak Pass area, or the shelfbreak south of the Pribilofs (Resource Areas 10 and 11 in the EIS analysis). These numbers can then be compared to risk criteria established by MMS for marine birds and gray whales. (It is not clear why the criteria are different. One could interpret "low" and "unlikely" to be similar categories, but MMS assumes that a "medium" risk for birds is a probability of 11-25 percent and an "unlikely" risk for gray whales is a probability of 11-30 percent. The important point is that the two sets of numbers for resource areas and species can be compared.) Clearly, the risk to birds and mammals is high in the vicinity of the Pribilof Islands and borders on high in areas along the shelfbreak south of the Pribilofs. Given the uncertainties involved in the estimated expected number of spills, the combined probability may have a confidence range that is wide enough to include more than one of the probability risk criteria.

This conclusion is particularly important when evaluating the summary of the FEIS and comparing it to the supporting documentation. The impact rating categories are clearly defined in the EIS, but it is not immediately clear that the rating in the summary integrates impacts from all activities (e.g., noise disturbance and oil spills). Using the definitions established by MMS and examining only conditional probabilities as discussed in the EIS, significantly different categories are noted even

Table 2-8. Reported Impact Assessment for Marine Birds and Marine Mammals

RESOURCE/ RESOURCE AREA	COMBINED PROBABILITY[a]		PROBABILITY RISK CRITERIA[b]			DEIS IMPACT RATING[c]	LARGE SPILL EFFECTS[d]
	%, 10 d	%, 30[d]	LOW %	MEDIUM (UNLIKELY) %	HIGH (LIKELY) %		
Pribilof Islands	33-34	44-46					
Unimak Pass	13	15					
Shelfbreak south of Islands	5- 9	14-34					
Marine birds			0-10	11-25	26-50	Mod.-Maj.	Major
Marine mammals[e]						Mod.	Major
Gray whale				11-30	31-60	Minor	Major
Fin whale						Minor	Mod.
Humpback whale						Minor	Mod.
Sperm whale						Negli.	Mod.

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[a] From Table E-10, probability a spill occurs from proposed action and hits target in "x" days. Averaged over all modeled launch points. Does not include cumulative case.

[b] Qualitative scale used in discussion of marine birds (DOI 1985, p. IV-46) and gray whales (in parens) (DOI 1985, p. IV-72).

[c] From Table S-1, integrates all activities (e.g., noise disturbance and oil spills) and classified as major, moderate, minor, negligible.

[d] Conditional probability, i.e., assumes a large spill occurs during summer in the vicinity of a species-specific high use area in lease sale.

[e] Noncetacean species.

when it is recognized that the reported conditional probabilities are annual means of the trajectories.

Chapter 3

OIL SPILL TRAJECTORIES

Summary

Winds are more important than ocean currents in determining spill trajectories. This chapter begins, therefore, with a brief discussion of the general climatology of the Bering Sea and how wind observations at the Pribilof Islands relate to the climatology. The purpose of the discussion is to describe major features of the weather that must be simulated if the trajectory analysis is to be adequate. It is not possible to discern from the EIS or its supporting documents what meteorological data are used or how they are used. Personal communication with Liu and Leendertse was necessary to determine that the information used in the model to simulate winds could result in reasonable trajectory simulations. The numerical model's ability to portray ocean circulation also appears reasonable, although apparently minor concerns remain about the model's "as-run" ability to accomodate monthly changes in density-driven currents.

Significant concerns remain about the adequacy of the number of trajectories currently used in the oil spill risk analysis. Evaluation of the risk assessment in the St. George Basin Sale 89 EIS suggests that the risk to targets during summer periods may be under-represented. Over half (58 percent) of the trajectory simulations are run for winter conditions, which may account for the apparent under-representation. It is not clear, however, whether under-representation also results from the manner in which overall risk is calculated or from the error inherent in the trajectory simulations.

Overview

Trajectory Evaluation

An important fact that stands out when one attempts to predict oil spill risks for a proposed OCS lease area is that the problem is fundamentally probabilistic. A great deal of uncertainty exists not only with regard to the location, number, and size of spills that will occur during the course of development, but also with regard to wind and current conditions that give direction to the oil at the particular times that spills occur. While some of the uncertainty reflects incomplete or imperfect data for which it is difficult to assign error bounds, the trajectory should be amenable to error analysis.

The purpose of the oil spill trajectory studies done for EISs is to assess the probabilities that oil spills from locations within a proposed lease area will reach specific targets. To accomplish this goal, a simulation is made of a number of trajectories of oil spills and then these trajectories are treated statistically. Oil spill trajectories in the Beaufort and Bering Sea regions are computed using a numerical model developed by Liu and Leendertse (1982) for the Rand Corporation. The model consists of two major features: one dealing with meteorological conditions, and the other with ocean circulation. The trajectories are then inserted into the MMS OSTA model (which is described by Smith et al. 1982) to evaluate the conditional probability of oil reaching the targets. The use of the Liu and Leendertse numerical model to predict trajectories is unique to Beaufort and Bering Sea EIS documents.

General Climatology of the Bering Sea

Movement of oil on the sea surface is directed by local wind and wave conditions and ocean currents. Should ice be present, it would modify the response of oil to the applied forces. The most important element in determining the trajectory of an oil spill, in both cases, is the wind.

The Bering Sea is affected by arctic, continental, and maritime air masses. In summer, the entire region is normally under the influence of maritime air from the Pacific. The southern portion of the Bering Sea is most frequently under the influence of maritime air, except during January and February (Grubbs and McCollum 1968) when normally a strong flow of air from the north and east brings in continental and arctic air. For the remainder of the year, the movement of low-pressure centers and associated winds dominate the atmospheric circulation in the southern Bering Sea.

A major influence on the general atmospheric circulation in the area is the region of low pressure normally located in the vicinity of the Aleutian Chain, referred to as the Aleutian Low. On monthly mean-pressure charts, this appears as a low-pressure cell normally oriented with the major axis in an east-west direction. This is a statistical low, indicating only that pressures are generally lower along the major axis as a result of the passage of low-pressure centers or storms. Storms are most frequent and more intense in this area than in adjacent regions. The most frequent track or trajectory of movement of these storms is along the Aleutian Islands and into the Gulf of Alaska in winter, and along the same general path in the west, but curving northward into the Bering Sea in summer (Overland 1981). The monthly frequency of low-pressure centers in the southern Bering Sea is slightly higher in winter (generally four-five) than in summer (three-four). Winter storms are much more intense than summer storms.

In winter, the most frequent airflow is northeasterly around the northern side of the low-pressure cell that is present at some location along the Aleutian Chain. In summer, with the movement of lows into the Bering Sea, a more southwesterly mean flow develops over the lower two-thirds of the region. Climatology of the southern Bering Sea is characterized by a progression of storms rather than fixed weather types (Overland 1981; Overland and Pease 1982). These storms produce increased cloudiness, reduced diurnal temperature range, and winds that rotate through the compass. During the summer in the southern Bering Sea, frontal activity can be severe as very cold arctic or continental air comes in contact with the warm air from the Pacific Ocean, forming a sharp discontinuity and localized winds.

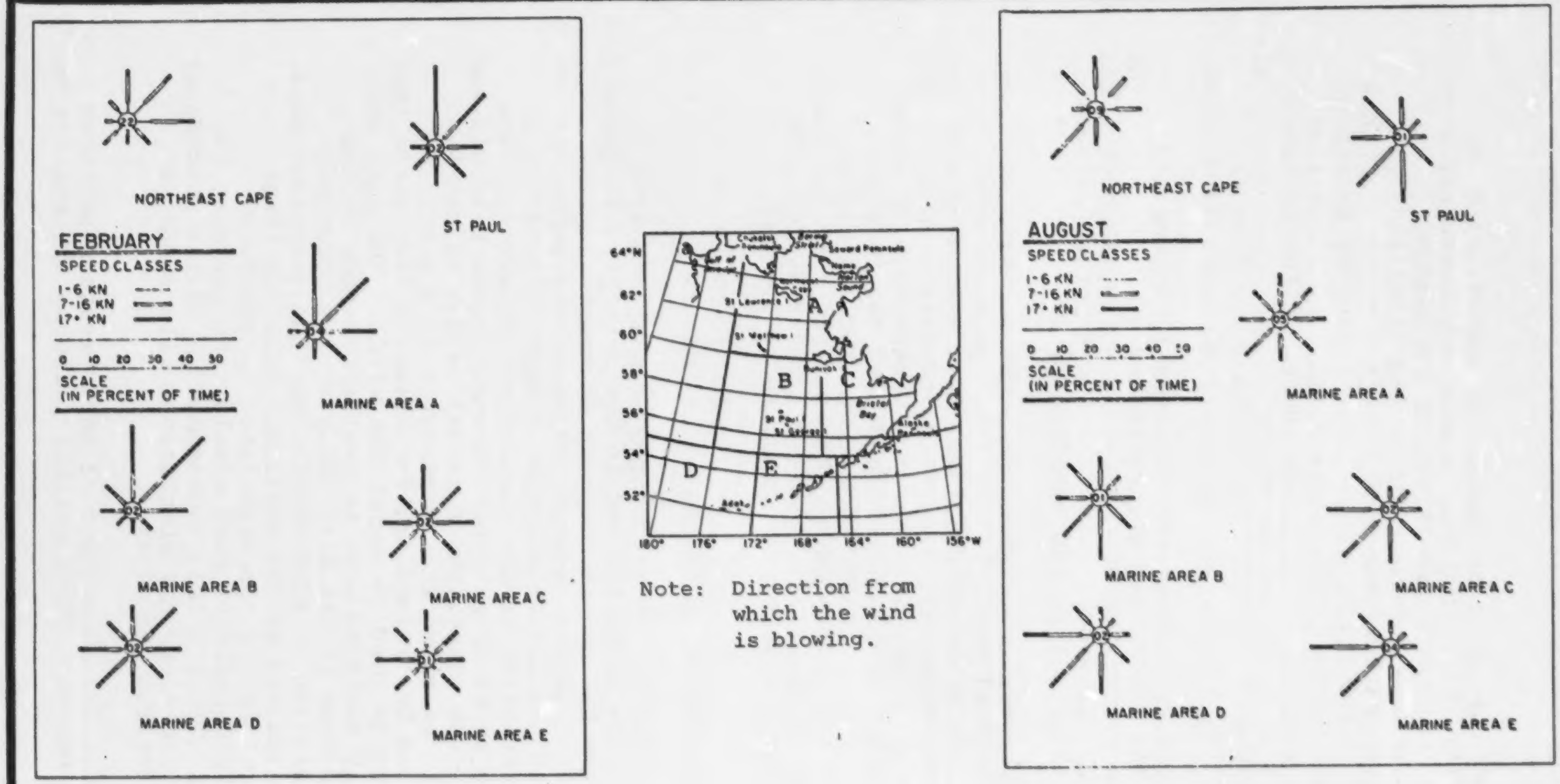
Figure 3-1 shows wind roses for selected locations and marine regions in the Bering Sea during February and August. The wind roses show the percentage of observations from each of eight possible directions. (The data were from Brower et al. [1977] and Grubbs and McCollum [1968] and compiled by Overland [1981].)

In winter ("February" in Figure 3-1), the northern stations show a high percentage of winds >17 kn from the north and northeast, whereas the winds over Bristol Bay (Marine Area C) are uniformly distributed over direction with moderately high speeds. This is indicative of a fairly continuous progression of storms through the area. Wind speeds over the Bering Sea in summer ("August" in Figure 3-1) are generally lower than in winter although conditions are seldom calm. Marine Area A to the north shows little preferred direction, but the other stations show predominance of south and southwest winds in the summer.

Simulation of Bering Sea Winds

This section concerns the procedures used by the Rand Corporation to simulate winds for use in the oil spill trajectory studies. Because the EIS and its support documents contain insufficient detail to permit reconstruction of the technical details, we met with Liu and Leendertse at Rand Corporation in order to obtain information on the simulation procedures. The discussion below is based on personal communications with Liu and Leendertse but does not constitute a formal review of the Rand programs. It should be noted that statements in the EIS and support documents can be misleading; for example, they state that Putnins' (1966) study is used to model the winds. The data are used but in a highly modified way; no mention is made of the modification or its form in the EIS. Many of the questions concerning the simulation of wind conditions that concerned this review team were discussed at the meeting. Based on these discussions, we conclude the approach taken by the Rand Corporation could be capable of wind simulations adequate for trajectory studies. Until a full documentation of the procedures is provided for peer review, the simulations will remain a concern to the scientific community.

Rand Corporation has identified 11 basic weather patterns for the Bering Sea region. These weather patterns are similar to



Note: Direction from which the wind is blowing.

FIGURE 3-1. FEBRUARY AND AUGUST WIND ROSES FOR DESIGNATED LOCATIONS (MAP) IN THE BERING SEA

SOURCE: OVERLAND 1981.

the more predominant patterns selected by Putnins (1966); however, they are also based on more recent meteorological data. The wind model uses these basic patterns and their frequencies and patterns of occurrence to simulate the large scale atmospheric features.

Since the Bering Sea region is one of frequent storm activity, the Rand simulation procedure interrupts the large scale weather patterns and inserts a traveling storm. For winter months, the simulated storms occur at a rate of four-five per month, and for summer months at a rate of three-four per month. In addition, Rand has carried out a study of the intensity and statistics of storm events in the Bering Sea region. These statistics are incorporated in the simulation procedures.

The simulation procedure has been shown by Rand Corporation (unpublished) to reproduce the observed wind roses at selected locations in the Bering Sea region. In the DEIS for the St. George Basin lease sale, it is stated that the wind model is verified because it reproduces the average wind speed and direction at Nome, Alaska. This is a gross over-simplification of the work that has been done at Rand Corporation. The simulation procedure contains more reality than is referenced in the EISs for the Bering Sea lease areas. However, the simulation procedure has not been documented nor has it been demonstrated that the analysis reproduces both the spatial and time scales which occur in actual Bering Sea winds.

The question concerning spatial and time scales of simulated winds is important to the trajectory analysis. When a trajectory evaluation is made, trajectories from a number of launch points are evaluated using the same simulated winds. If these winds have larger spatial patterns than the launch point separations, then adjacent trajectories will not be statistically independent. Consequently, it is important that the scales of atmospheric forcing be simulated correctly.

Simulation of Bering Sea Circulation

Oceanography of the Bering Sea

The reason that a numerical model of ocean circulation was used for Bering Sea leases is that the region has strong tidal currents, is subjected to strong wind events, and has domains in which horizontal density gradients are large. Furthermore, the shelf circulation has regimes which are distinctly different as to the influences of bottom friction, thermohaline processes, and oceanic influence. The inclusion of a dynamic model in the risk analysis study is intended to increase the reliability of oil spill trajectory estimates.

The Bering Sea continental shelf is broad (500 km) and the bottom grades smoothly offshore to a relatively deep (170 m) shelfbreak, with the 50 and 100 m isobaths dividing the shelf into three zones with distinguishable water column characteristics. The 50 m contour lies 80-150 km from shore, and the 100 m contour is 100-150 km landward of the shelfbreak, leaving a central region over 200 km wide with intermediate depths.

The dominant water motion on the shelf is by tidal currents, which are relatively strong (20-50 cm/sec) and account for 60-90 percent of the horizontal kinetic energy. Turbulent energy for mixing the water column comes from only two sources: tidal currents (up from the bottom) and wind (down from the surface). During winter and spring, the wind-mixed layer is 10-70 m thick, with an average thickness of about 50 m. In summer, this layer is 5-20 m thick, with an average value of about 10 m. The tidally mixed bottom layer is 30-50 m thick. Over the inner shelf (depths <50 m), these wind and tidal boundaries merge, creating a well-mixed water column. Over the middle shelf (depths 50-100 m), the boundary layers are separated. The layer between has no significant source of turbulent mixing energy. It is within this central part of the water column that shelfwater is working its way seaward. Over the outer shelf, oceanic water penetrates inward beneath the outflowing water from the middle shelf.

The circulation described above is weak with horizontal currents generally <4 cm/sec. Tidal currents are much stronger; however, tidal motions are elliptical. It terms of transport of oil over time spans of 3-30 days, neither the weak mean flows associated with the distribution of temperature and salinity over the Bering Sea shelf nor the tidal currents are of predominant importance. The wind-driven currents dominate in the transport of oil on the sea surface. The wind-driven currents fluctuate on periods of 2-10 days, with magnitudes up to 20 cm/sec (Schumacher pers. comm.).

In addition to the wind-driven circulation over the Bering Sea shelf, there are strong currents along the continental shelf between Unimak Pass and the Pribilof Islands. These currents fluctuate at periods longer than 10 days, and the fluctuations are not apparently related to local wind events. The average speed of the currents is about 6 cm/sec; however, currents as high as 20 cm/sec and as small as 2 cm/sec may be found (Schumacher pers. comm.). The general direction of flow is along the shelfbreak to the northwest. During the summer of 1977, six satellite-tracked drifters (drogued at 17 m) were deployed over the shelf/slope break. Vector mean speeds were 5-15 cm/sec over deeper water and 1-3 cm/sec in the shallower shelf waters. The buoys drifted towards the northwest.

The Numerical Model

The basic 3-dimensional model developed by Liu and Leendertse solves the equations of motion for water and ice, continuity, mass, heat, salt, pollutant, and turbulent energy balance. Implicit numerical solution methods are used in the vertical so that cross-layer transfer of momentum, energy, and constituents can be computed accurately without any numerical stability problems. The model was first described by Leendertse et al. (1973) and again by Leendertse and Liu (1977). Improvements to the model which have been made since these publications include:

- The horizontal grid structure includes the ellipsoidal curvature of the earth.
- Ice dynamics (including melting, salt rejection, and ice-ice interactions) are included in the formulation.
- A parameterization of oil movement under ice is in the formulation.
- The model incorporates a closed form for the generation and decay of turbulence. This form no longer depends on the Richardson number and related parameters.
- The model includes the kinetic energy content and dissipation associated with short wind waves.

No substantial changes in the model have been made since 1981. Consequently, all studies of oil spill trajectories have been carried out with the same formalism.

The 3-dimensional model can be used directly for simulating oil movements for a duration of several days. For longer periods (such as several months), a much more economical method is needed. To accomplish this, Rand uses a method called the unit response function method. Response functions, after being generated by the 3-dimensional model under four wind directions (N,E,S,W), are used to synthesize, through a convolution process, the drift currents due to winds from various weather scenarios. Response functions are generated by the difference in currents in the 3-dimensional field with and without the wind stress under identical tide conditions. The model is run for 5 days; the first 3 days of information are discarded because they are contaminated by start-up transients in the model. The last 2 days of data are used to evaluate the response functions and average flows.

Boundary conditions used in the simulations are based on field observations. For the shelfbreak currents between Unimak Pass and the Pribilof Islands, historical hydrographic data have been used to determine the density field and geostrophic currents. The model uses a shelfbreak current of 6 cm/sec flowing towards the northwest. Over the shelf proper, the initial data for the model's density field are based primarily on observations gathered in 1976 by the NOAA research ships _Moana Wave_ and _Miller Freeman_. Tide data at the open boundaries, which are based on observations, complete the required suite of boundary conditions.

Verification

Mofjeld (1984) has compared observations of tides with predictions made by the 3-dimensional Liu and Leendertse model and by a vertically integrated hydrodynamic model (Sundermann 1977). Mofjeld concludes that the quantitative agreement with observations is better for the 3-dimensional model. He states, "This may be due to the more complete dynamics in the 3-dimensional model as well as the tuning of this [3-dimensional] model to a larger set of tide observations than was available to Sündermann (1977)." The simulations were for summer conditions. The comparison employed predictions from a preliminary calculation using the 3-dimensional model; more recent work may demonstrate further improvements. Even without further improvements, the 3-dimensional model has been shown to predict a reasonably accurate tide picture for the Bering Sea region. This could not result from the calculations if the model was incorrectly evaluating tidal dissipation.

Ice

The Rand model allows for ice cover in the oil spill trajectory studies. Ice, particularly near the ice edge, adds several complications to the prediction problem. Muench (1983) and Muench and Schumacher (1985) discuss the results of recent experiments. One important process is the melting of the ice, which creates a freshwater lens near the limit of ice flow. The density contrast between this fresh water and the more saline waters of the ice-free regions of the continental shelf generates a northward-flowing baroclinic current parallel to the edge of the ice zone. This current, coupled with reduced mobility of sea ice (relative to open water), diminishes the importance of local winds relative to baroclinc flows in transporting oil. Trajectories of oil spills generated by the Rand model show this effect.

An average ice cover year is assumed for the model runs. The actual marginal ice zone is not fixed in space but varies with wind conditions. It does not appear that the Rand model can include this variability in the trajectory calculations. This is because the calculations use response functions that are fixed by the ocean state at the beginning of the simulation. Thus, the variability in trajectory paths related to the position of the marginal ice zone may be underestimated in the calculations.

The EIS and its supporting documents inadequately describe the model run with ice cover. The documents state only that the model was run with ice cover. In fact, the model 'with ice cover' refers to a model formulation capable of incorporating ice cover. For the trajectory studies, winter conditions were simulated by using six trajectory simulations for each of 6 winter months. For each simulation, the marginal ice zone was located at its multi-year average location for the month.

Influence of Numerical Model on Trajectory Analyses

A review of the trajectory analysis is severely hampered by a lack of documentation of the details of the calculations. When tests and checks have been made, they should be cited in the references in the EIS. Because our major goal has been to consider reasonableness of the approach, we have looked at the results as the output of a 'black box' and tried to understand its significance in predicting conditional risk percentages. It is not necessary that details of the calculations or formulations be described in the EIS. It is necessary, however, that the EIS provide enough information about what data are used in model formulation and an overview of how they are used so that it is possible to determine whether important factors in trajectory simulations are accounted for. Our review suggest that the model and resulting trajectory analyses are reasonable, although two concerns remain: first, regarding the model's ability to address short-term (monthly) changes in baroclinic currents; and second, regarding the model's ability to address effects of freshwater runoff.

Baroclinic Currents

The evaluation of trajectories of oil spills relies heavily on the use of response functions derived from the continental shelf circulation model. These response functions are derived from model runs a few days long (after allowing for startup transients in the calculations). The use of these response functions implies that they contain all of the relevant physics and dynamics of the ocean circulation.

The purpose of a multi-layered numerical model is to include baroclinic processes in the calculations. Since the response functions are fixed in space and derived from the density field imposed when the model run is begun, any effects due to short-term advection of the density field are lost. If wind forcing moves the density field or alters horizontal density gradients, the resulting changes in circulation cannot be evaluated. New response functions would need to be derived based on the new density field, and this step would negate the numerical economy achieved by using response functions.

Since baroclinc currents are weak (<10 cm/sec) over most of the Bering Sea shelf, the errors made in their evaluation may not seriously hamper the trajectory evaluations. If the model were extended to oil in water calculations, however, errors in evaluating baroclinc flows could become more important.

Freshwater Runoff

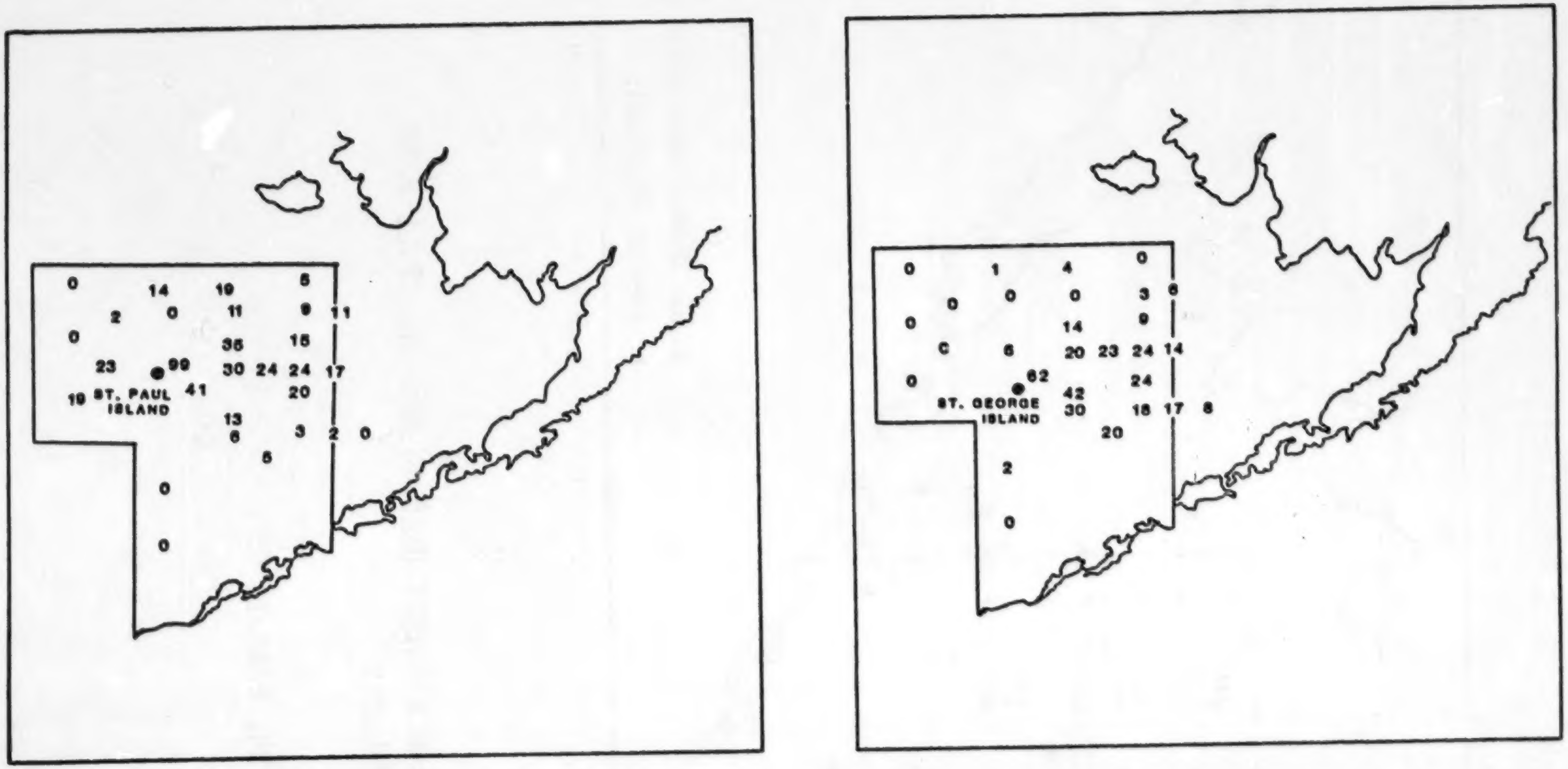
If fresh water were to enter the system, e.g., from major rivers such as the Yukon, the influence of this lens of water is not accounted for unless it is present in the response functions. Runoff can vary appreciably over periods of 30 days, particularly in spring time. This temporal variation of input of fresh water would not be included in the response functions, and the resulting calculations could be in error. Since effects of runoff are localized, the errors need not have a major impact on the shelf as a whole, but they could appreciably alter local calculations in areas such as Norton Sound or inner Bristol Bay.

These comments are not to be interpreted as a statement that the Rand model is incapable of evaluating baroclinic flows or freshwater runoff. We note that, as used in the trajectory analysis, the model cannot properly reproduce short-term changes in baroclinic flows. Regions where such flows are important include: the marginal ice zone, regions with high inputs of fresh water, regions with time-variable input of saline water (the most predominant is Unimak Pass), and the region near the 50 m contour.

Interpretation of the Trajectory Studies

Figure 3-2 was prepared from the risk tables in the FEIS for the St. George Basin lease sale (DOI 1985, Table E-3). The launch points in the lease sale area are labeled in Figure 3-3 using the notation in Table E-3. Figure 3-2 shows the overall combined risk probabilities for the resource areas around St. George and St. Paul Islands (Figure 3-4). The resource area is defined by a circle of radius 50 km about each island. Figure 3-2 shows that the majority of the risk comes from within the quadrant to the east of the islands. Although risk to St. George Island is minimal from the south and west, similar findings are not made for St. Paul Island. Overall, the patterns of probability are not inconsistent with wind rose data for the winter (Figure 3-1). In summer, however, the wind rose for St. Paul Island shows more persistent winds from the south, southwest, and west (Figure 3-1). These pictures raise a question concerning the true risk to the Pribilofs because it seems that summer weather is not adequately represented in the statistics.

One way to interpret Figure 3-2 is to assume that differences in the probabilities of contact to a target from nearby locations represent the overall statistical accuracy in the calculations. For example, in Figure 3-2 there are two nearby launch points to the southeast of St. George Island: one has a probability of 42 percent of contacting the St. George resource area and the other a 30 percent chance. Since the locations are nearly the same, it could be assumed that the internal consistency in the calculations is about 12 percent. Similarly, north of St. Paul Island, there is a launch point with a 14 percent probability. A launch point nearly an equivalent distance north of St. George Island has a 0 percent chance of resulting in a spill that reaches the St. George resource area. This suggests an internal consistency in the simulation procedure of about 10-15 percent.



0 14 19 5
2 0 11 9 11
0 35 15
23 99 30 24 24 17
19 ST. PAUL ISLAND 41 20
13 6 3 2 0
5
0
0
0 1 4 0
0 0 0 3 6
0 14 9
C 6 20 23 24 14
0 62 24
ST. GEORGE ISLAND 42 30 18 17 8
20
2
0

NOTE: VALUES INDICATE PERCENT PROBABILITY THAT A LARGE OIL SPILL OCCURRING AT THAT POINT WILL REACH PRIBILOF ISLANDS WITHIN 30 DAYS.

FIGURE 3-2. MMS-CALCULATED RISK TO PRIBILOF ISLANDS RESOURCE AREAS

SOURCE: DOI 1985, TABLE E-3.

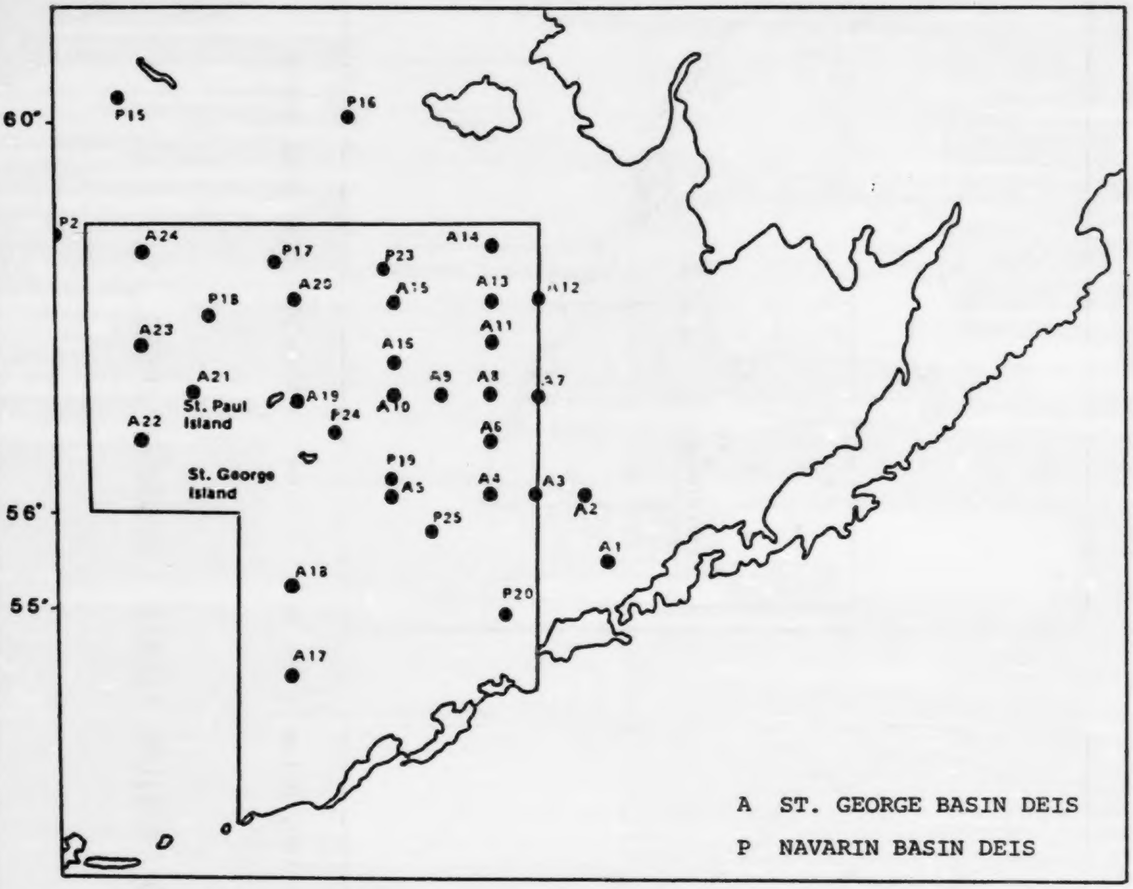

60°
56°
55°
P15
P16
P2
A24
P17
P23
A14
A20
A15
A13
A12
P18
A23
A11
A15
A21
A19
A10
A9
A8
A7
St. Paul Island
A22
P24
A6
St. George Island
P19
A5
A4
A3
A2
P25
A1
A18
P20
A17
A ST. GEORGE BASIN DEIS
P NAVARIN BASIN DEIS

FIGURE 3-3. LAUNCH POINTS USED IN MMS OIL SPILL RISK ANALYSIS

SOURCE: DOI 1984, GRAPHIC 5.

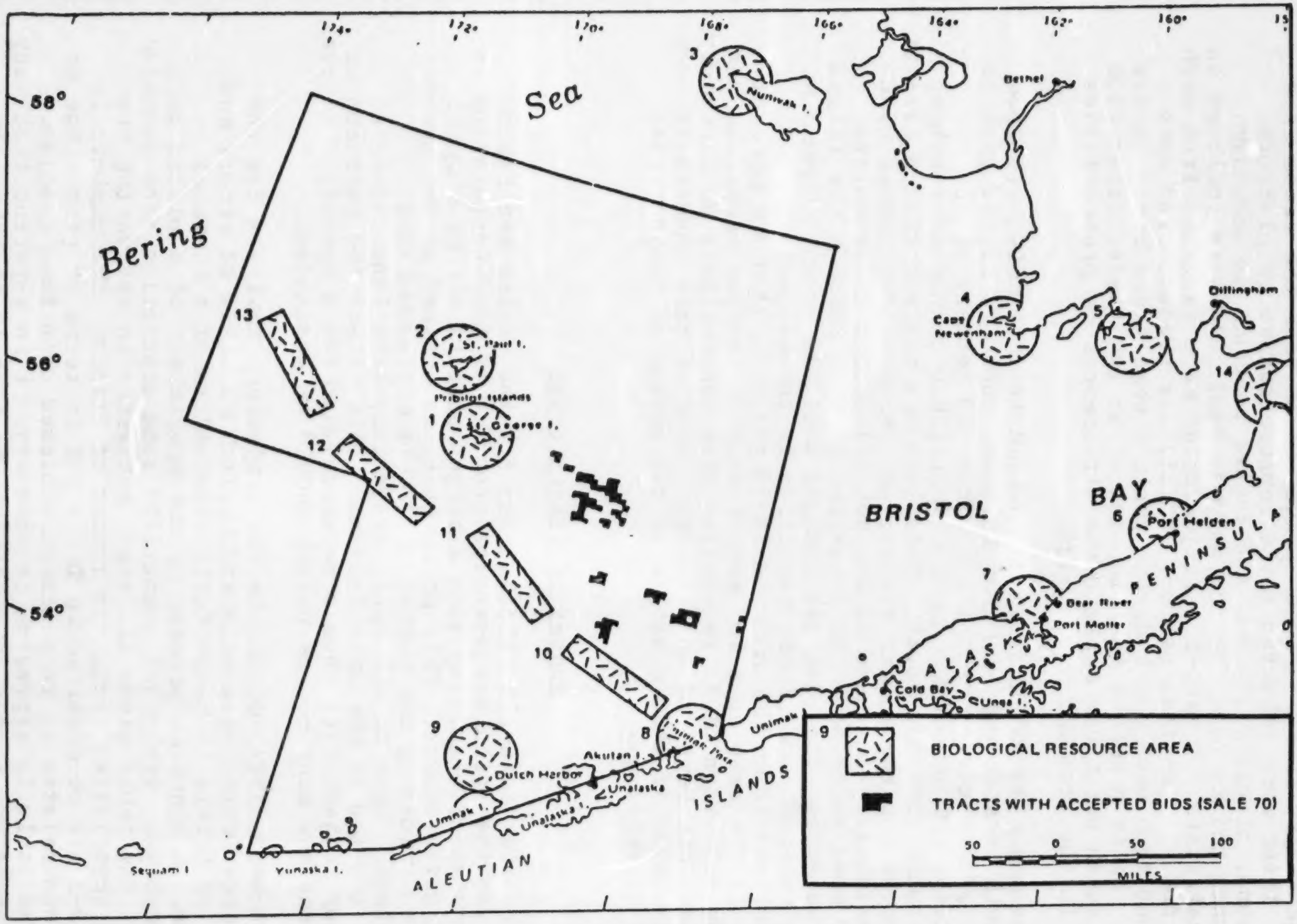

174°
172°
170°
168°
166°
164°
162°
160°
58°
56°
54°
Bering
Sea
3
Nunivak I.
Bethel
4
Cape Newenham
5
Dillingham
14
13
2
St. Paul I.
Pribilof Islands
1
St. George I.
12
11
10
BRISTOL
BAY
6
Port Heiden
PENINSULA
7
Bear River
Port Moller
ALASKA
Cold Bay
Unga I.
9
Dutch Harbor
Akutan I.
Unalaska
Unalaska I.
Umnak I.
8
Unimak Pass
Unimak
ISLANDS
ALEUTIAN
Seguam I
Yunaska I.
9
BIOLOGICAL RESOURCE AREA
TRACTS WITH ACCEPTED BIDS (SALE 70)
50
0
50
100
MILES

FIGURE 3-4. BIOLOGICAL RESOURCE AREAS FOR ST. GEORGE BASIN OIL SPILL RISK ANALYSIS

SOURCE: DOI 1984, FIGURE E-2.

For the St. George Basin EIS, simulated oil trajectories were generated from 24 launch points in or near the lease sale area. These were selected to be representative of platform locations, pipeline routes, and tanker routes. In addition, 26 launch points used for the Navarin Basin EIS were included in the statistics. Twenty-six trajectories were launched from each point for the ice-free season. Thirty-six trajectories were launched from each point during periods when there could be ice cover. It is possible that the use of so few trajectories from each launch point can explain the differences in probabilities noted in the preceding paragraph.

Because the winds in winter do not tend to drive oil from the south towards the Pribilof Islands, there is little risk to these islands during this time. Thus, 58 percent of the tractories (36 out of 62) have a negligible chance of reaching the Islands from the south. This leaves a maximum chance left of 42 percent for the summer tractories. With weaker summer winds and variability in these winds, not all summer trajectories should move northward. If a quarter of them reached the Island resource areas, the risk percentages would be about 10 percent. If the inherent statisical variation in the trajectory evaluations is on the order of 10-15 percent, then a 0 percent chance is the same as a 10 percent chance. Proper decisions can be made only when it is recognized that the analysis as currently done has this level of uncertainty. Some of this uncertainty may be eliminated if this question of the number of trajectories needed is resolved.

Number of Trajectories

The risk anlaysis calculations for the Bering Sea lease areas use the spill trajectories provided by Rand Corporation to evaluate the probability that a target area is hit by a spill from a given source. This probability is defined as the number of hits divided by the number of spills expressed as a percentage. Once an oil spill trajectory hits land, it is no longer counted in the calculations. This raises the question of how many trajectories should be calculated for a specified source point and how many source points should be evaluated.

Samuels (1984) documents the trajectory analysis for the St. George Basin lease sale and includes a table of errors and number of trials in Monte Carlo simulations of a binomial process. A binomial process is the equivalent of a biased coin toss problem. Table 3-1 summarizes some statistics from Samuels' table. The table gives the error estimates in estimating the true probabilities given the number of trials. The numbers in Table 3-1 are re-examined in Table 3-2 in terms of percentage of error and relates it to a biased/unbiased coin toss problem. When the table is expressed in this way, it is apparent that many experiments are needed to determine the bias in an extremely biased coin, while relatively many fewer are needed to determine the probabilities in an unbiased coin.

Table 3-1. Monte Carlo Error as a Function of Number of Trials and Estimated Probability

	Number of Trials						
Prob	10	40	50	100	500	1000	2000
0.02	0.07	0.04	0.03	0.02	0.01	0.01	0.01
0.50	0.26	0.13	0.12	0.08	0.04	0.03	0.02

SOURCE: Samuels 1984, Table 2.

Table 3-2. Percent Error for a Biased (P=0.02) and Unbiased (P=0.50) Coin.

	Number of Trials						
Prob	10	40	50	100	500	1000	2000
0.02	350	200	150	100	50	50	50
0.50	52	26	24	16	8	6	4

Note: Derived from Table 3-1.

Applying this model to the true probability that oil spills might strike a specific land segment vs. the calculated probabilities that oil strikes the land segment, we observe that many trials are needed to adequately model low risk areas and few trials are needed to model high risk areas. We note, however, that the percentage of error is large even with 2,000 samples of a coin with extreme bias. Table 3-2 suggests that for the trajectory calculations in which 62 trials are used, there should be inherent errors between about 24 and 150 percent.

An alternative method for viewing trajectory experiments can be expressed by the following thought experiment, which is geometrically similar to the trajectory problem. Suppose we randomly generate 36 spokes radiating from the center of a circle that has been divided into 36 arcs each of 10° width. For any arc, the mean expected number of spokes hitting the arc will be one; however, the standard deviation in the number of spokes in a given arc is four. Thus, in a specific experiment, it would not be unusual to have several arcs with zero spokes and a few arcs with four-five spokes. In terms of risk analysis made utilizing a single sample, one arc would have four-five times the risk of others, even though its true risk is identical to other arcs. In the models of trajectories, the oceanographic and meteorologic influences will tend to focus trajectories. Thus, statistics from thought experiments, such as this, are conservative.

Our concern with regard to the risk analysis presented for Bering Sea lease areas is that the analysis of the trajectories not introduce a bias and that they are sufficient in number to eliminate statistical variations in the assessment of risk. The documents supporting the EIS have failed to address this question.

During the meeting with Rand Corporation, Liu presented an overhead slide showing that independent calculations of trajectories by Overland (PMEL unpublished), which were based on actual weather sequences, had the same qualitative character as Rand predicitions. The predictions were for an open ocean region south of the Pribilofs. One way to look at this result is that the Rand model is not predicting significantly different results from what a 3.5 percent of surface wind-speed model would give. In the Rand model, a 1.6 percent of wind-speed rule is used to account for Stokes drift due to surface waves. The remaining difference of 2.9 percent is included in the air-sea interaction simulations.

The approach to the trajectory analysis appears to be reasonable. Although ambiguities in the risk analysis procedure appear to be of little importance as the model is now used, we do not believe that these ambiguities should continue. The most serious concern is that the risk to specified resource areas is not adequately represented because the number of trajectories is too few and perhaps biased toward winter conditions. Whether this is the case cannot be determined until additional trajectories are run so that error bounds can be evaluated.

Chapter 4

CONCLUSIONS AND RECOMMENDATIONS

Overview

Our review and evaluation of the oil spill risk analysis as presented by the St. George Lease Sale 89 EIS (DOI 1984, 1985) and its support documents lead us to the following major conclusions:

- There is considerable uncertainty in the spill risk estimate (expected number of spills).
- Given the inherent uncertainty in the estimate, the approach and the reported estimates appear to be reasonable approximations.
- The wind simulation technique appears to be reasonable and adequate for offshore lease sales in the Bering Sea but has not been documented.
- It is not clear that the number of simulated trajectories is adequate to portray the risk to designated targets, especially once the probability distribution for trajectories is adjusted by mean-case production data to generate combined probabilities.
- The presentation of the oil spill risk analysis in the EIS can and should be improved in several significant ways if it is to meet NEPA requirements.

Sources of Uncertainty

There are four main sources of uncertainty in the risk evaluations. These are:

1) Uncertainties in the resource estimates.
2) Uncertainties in the expected number of spills because of the small database from which means have been derived.
3) The distribution function for spill frequencies is only approximated by a Poisson distribution. Therefore, estimates of the probabilities of number of spills will be increasingly uncertain as the number differs from

the mean estimate. Similarly, spill size forecasts will increase in uncertainty as the forecast departs from the mean spill size.

4) The scenarios for production introduce additional uncertainties.

In the DEIS for Lease Sale 89 (DOI 1984), the mean resource estimate was 0.66 Bbbl. In the FEIS for Lease Sale 89, the mean resource estimate increased to 1.12 Bbbl. In the 1981 synthesis meeting, the mean resource was listed as 1.12 Bbbl. Finally in the Federal Offshore Statistics (Essertier 1984, p. 98), the mean resource estimate for St. George Basin is listed at 1.4 Bbbl. The final risk estimates are linearly related to these resource estimates. Thus, the final risks have inherent in them the uncertainties in resource estimates.

For spills $\geq$100,000 bbl, spill rates are much less accurate and much less deterministic than for smaller spills. This is unfortunate because these very large spills are more likely to have major and long term environmental consequences. The projected spill rates are based on an extrapolation of a log-normal distribution fit to the frequency distribution for spill volume. Extrapolation of a log-normal distribution beyond the set of date it was fit to is usually not attempted because almost no confidence can be placed on the extrapolated estimate. The FEIS (DOI 1985) presents the risk rate for very large spills as if it had the same certainty as smaller spills. This is misleading, particularly when one considers that the spill rate for even smaller spills are characterized by great uncertainty.

Interpretation of the Oil Spill Risk Analysis

On several points, we conclude that the EIS interpretation of the oil spill risk analysis requires improvement. The majority of these points focus on two major concerns: 1) the tendency to average out findings that either should not be or cannot be averaged, and 2) incomplete presentation of information necessary to judge the reasonableness and adequacy of the findings.

By averaging the impact levels from various activities associated with the lease sale, the significance of the impact from oil spills is often obscured. This problem is most noticable in the EIS summary. For example, although the EIS may determine that impacts from seismic exploration activity may be negligible and impacts from oil spills may be moderate for a certain species, the EIS summary concludes that the "overall risk" to the species is minor. This approach violates a fundamental principle of ecology which states that the presence and success of an organism or group of organisms depends on that one condition that most closely approaches or exceeds the limits of tolerance. Thus, the "overall impact" of a project is no less than the most severe impact likely from any particular aspect of the lease sale activity. In a similar vein, "overall risk" to a higher taxon (e.g., crustaceans or marine mammals) cannot be the average of the risk to each species.

The EIS also averages out seasonal differences in trajectory simulations. Averaging may be a reasonable approach in calculating combined probabilities as long as this point is clearly stated and seasonal differences are given weight proportional to their occurrence. This latter point is particularly important because of significant summer use of the area by marine birds and mammals. Since 58 percent of the trajectory simulations for Sale 89 are run for winter conditions, a bias away from summer trajectories is incorporated in the analysis. Thus, the conditional probabilities and combined probabilities reported in the EIS are averaged over the annual meteorological and oceanographic conditions and weighted more toward winter conditions.

References to incomplete documentation have been noted several times in previous chapters. In several cases, the missing information is important to interpreting the reasonableness and adequacy of the impact assessment. The most important omissions are:

- the general features of the wind simulation model;
- a clear statement of the important assumptions underlying the estimated expected number of spills;
- an explanation of how the launch points have been weighted for volume of oil handled; and
- clear statements regarding the implications of the way certain information is treated.

This latter point is particularly important. CEQ regulations require a worst-case analysis when great uncertainty is inherent in the analysis (40 CFR 1502.22). We believe it is reasonable to present conditional probabilities that have been averaged out for all seasons, for example, but the decision maker and the public must recognize that the conditional probabilities in reality will be higher or lower for certain seasons. It is the responsibility of the EIS to clearly state implications such as these.

Recommendations

We recommend that EPA give greater emphasis to conditional probabilities when determining the environmental consequences of a proposed action. Greater reliance on the conditional probabilities is, of course, predicated on: 1) a larger number of trajectories per launch point, 2) proper balance between seasonal conditions, and 3) clear understanding that these values are averaged for the life of the project. The combined probabilities are of value in that they provide a rough estimate of the likelihood of a particular spill event/impact, but they should not be used in a deterministic manner because of the large uncertainties in the expected number of spills. We believe our recommended approach is more appropriate because it more closely approximates a reasonable worst-case analysis, which is required by CEQ regulations when great uncertainty is involved.

An adequate worst-case analysis should include a discussion of conditional probabilities for the summer season. This represents the period of time when most birds and mammals are at greatest risk. Basing the analysis on conditional probabilities that have been averaged out over the year would not result in a reasonable worst-case analysis.

MMS should not continue to report "overall risk" to a species as an average of the risks posed by different aspects of the lease sale action. The practice has no biological value and is misleading.

Sufficient numbers of trajectories should be simulated so that error bounds on the probabilities can be assessed. We also recommend that the number of trajectories be proportionately distributed among the seasons if annual averages are going to be used.

The EIS must do a better job of describing the Rand model. We do not recommend that MMS describe the mathematical details of the trajectory simulation models, rather, it is recommended that a brief explanation be given of the factors considered in model runs. For example, the reader must know: traveling storms are simulated at a frequency that resembles actual conditions in the Bering Sea; how the number of trajectories are allocated to different months for the winter simulation; where the marginal ice zone was for each winter simulation. This level of information is necessary to judge the adequacy and reasonableness of the risk assessment. We suggest that Rand publish a document that concisely states the model's adaptation to the trajectory studies, its meteorological inputs, and the tests that have been made of the model. We also suggest a careful analysis be conducted of the error bounds associated with the trajectories.

We recommend that the critical assumptions of the oil spill risk analysis be clearly stated. In most cases, MMS has stated the assumptions at various points in the EIS. However, we believe the presentation can be significantly improved if these are brought together in one location to clearly reveal to the reader the information necessary to judge the credibility of the analysis. As an example, we believe Table S-2 (DOI 1985) is a commendable example of how important assumptions can be presented to the reader. In this context, the reader can judge for himself whether the terms as applied to endangered species (for example) are appropriate and should be equivalent to those applied to nonendangered cetaceans.

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Appendix A

EVALUATION OF OIL SPILL RISK

Spill Occurrence as a Poisson Process

The principal reference for the Poisson model used in the EIS is a USGS Open File Report by Anastase Nakassis (Nakassis 1982). The abstract for this paper is short and to the point:

> "ABSTRACT: In what follows we examine the hypothesis that there has been no improvement in the offshore oil production safety [versus] the hypothesis that there has been a gradual improvement. Our analysis will show that the second hypothesis is much better supported by the available data."

The report is referenced in the supporting documents to the EIS to indirectly suggest that the modeling of oil spill frequencies is correctly done with a Poisson process based on a modified oil production variate as an exposure variate. For example, Lanfear and Amstutz (1983) state that they treat oil spill occurrence as a Poisson process. Their justification and methodology are based on Nakassis (1982).

We conclude that Nakassis' report does not show that oil production is an appropriate exposure parameter. Rather, Nakassis first shows that production is not a good exposure variate; and then he attempts to transform the data to create a better exposure variate under the assumption that oil spills are caused by a Poisson-like process. The validity of the transformation that Nakassis uses rests on the Poisson assumption but does not verify the assumption.

Tests of Oil Spill Occurrence Patterns

The Nakassis report first examined the question, "Is there any statistical evidence that we are not dealing with a Poisson process whose parameter is proportional to the oil produced?" Four different statistical procedures were used and, without exception, all suggested that the data do not support the proposed model, i.e., the relationships between the intervals between spills are not like those predicted for a Poisson process.

The underlying property exploited by Nakassis to test the model is that the waiting time between Poisson-distributed events is identically and independently distributed. This allows the use of distribution-free statistical tests (including tests of runs and rank-order correlations) and tests based on parameter-free ratios of summations; all of these were employed by Nakassis. The database employed by Nakassis consisted of nine spills that occurred between 1 January 1964 and the end of 1980. The data consist of the dates of the nine spills and the amount of oil produced in federal OCS waters between spills. There is, however, one important exception: the amount of oil produced prior to the first spill in the database (8 April 1964) is presumed to be the amount of oil produced between 1 January and 8 April 1964.

Nakassis accepts, without discussion, 1 January 1964 as an acceptable starting date for calculation of the exposure prior to the first spill in his database. This is somewhat controversial. The selection of 1 January 1964 results in an exposure of 31.3 million barrels (Mbbl) for the first spill, whereas the cumulative OCS production prior to 1964 was 380 Mbbl. One could argue that 31.3 is not a very likely draw from the population. More significantly, the tests of runs and rank-order calculations would be less conclusive if the exposure prior to the first spill were changed only slightly.

We believe it would be preferable to use the date of the first spill as the beginning of the first interval to be analyzed. If we change the starting date from 1 January 1964 to 4 April 1964, we change the statistics calculated by Nakassis. Most importantly, we reduce the number of inter-arrival intervals from nine to eight. With respect to Lanfear and Amstutz's analysis, we reduce their number of intervals from 12 to 11. These changes do not alter the conclusion that the data are not independently and identically distributed.

Table A-1 shows the modified form of Nakassis' data. (We also recalculated the production values and found some slight discrepancies with Nakassis' results.) The statistical tests we applied to the data are Kendall's τ and Q parameters which compare rank ordering between two lists. The rank orderings we use are based on the date of the spill (list 1) and the inter-arrival production (list 2). The statistical test suggests that the two lists are positively linked (the chance that they are not is 0.27 percent), which implies that longer inter-arrival intervals occur at later dates. This is not consistent with a Poisson distribution. The same test applied to Lanfear and Amstutz's data (Table A-2) showed that the chance of independence of their data is 2 percent.

Thus, correcting the starting value and using two spills in October, 1964, we still concur with the paper's conclusions regarding the import of these tests. Specifically, Nakassis states:

> "Thus it seems that there are excellent reasons to reject the hypothesis that the random variables $X_1, X_2, \ldots X_n$ are identically distributed and independent."

Table A-1. Test of Poisson Fit to Arrival Times Between Spills: Modified Nakassis Data

REF NUM	SPILL DATE	PRODUCTION INTERVAL TIME NAKASSIS	PRODUCTION INTERVAL TIME RECALCULATED	RUNS	RANK	STATISTICS
1	08-Apr-64	0				
2	03-Oct-64	55.9	55.9	-	2	Kendall:
3	09-Jul-65	103.1	98.8	-	3	T = 25
4	23-Jan-69	712.9	716.9	+	6	I = 3
5	16-Mar-69	43.5	42.0	-	1	S = 22
6	10-Feb-70	270.5	272.6	-	4	Tau = 0.785
7	01-Dec-70	272.5	271.5	-	5	Chance of
8	09-Jan-73	804.9	811.2	+	7	being
9	23-Nov-79	2054.3	2064.0	+	8	Poisson = 0.275%
		Mean =	541.6			

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[a] First spill noted by Nakassis is assumed to be the beginning point of the modified data set, i.e., the first spill noted by Nakassis is not included in determining run sequence and not ranked.

Table A-2. Test of Poisson Fit to Arrival Times Between Spills: Lanfear and Amstutz Data

REF NUM	SPILL DATE	PRODUCTION INTERVAL TIME NAKASSIS	PRODUCTION INTERVAL TIME RECALCULATED	RUNS	RANK	STATISTICS
1	08-Apr-64	0				
2	03-Oct-64	55.9	55.9	-	2	Kendall:
3	19-Jul-65[a]	103.1	102.6	-	3	T = 41
4	28-Jan-69[b]	712.9	717.3	+	10	I = 14
5	16-Mar-69	43.5	38.0	-	1	S = 27
6	17-Aug-69		124.6	-	4	Tau = 0.490
7	10-Feb-70	270.5	147.9	-	5	Chance of
8	01-Dec-70	272.5	271.5	+	8	being
9	20-Jul-72		632.7	+	9	Poisson = 2.027%
10	09-Jan-73	804.9	178.5	-	6	
11	23-Nov-79	2054.3	2064.0	+	11	
12	17-Nov-80		252.5	+	7	
		Mean =	416.9			

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[a] Nakassis reports 9 July 1965 (see Table A-1).
[b] Nakassis reports 23 January 1969 (see Table A-1).

Although it is not explicitly stated as such, a necessary corollary to this finding is that the spill process is not well modeled using a Poisson process with production as an exposure parameter. This is because some of the properties that distinguish Poisson processes are 1) that they have no memory and 2) that intervals between events are therefore identically and independently distributed. Any finding that suggests that the data are not independently and identically distributed also rejects any hypothesis of Poisson behavior.

The Idea of Time-Varying Rate Parameters

Nakassis next asks the question: "Can a better model be constructed using the idea that the rate parameter has declined with time?" The idea for this approach is reasonable, and it is strongly suggested by the analysis. As a result of the increased concern over oil spillage, it is presumed that the industry has improved its practices and consequently its safety record over time and that the frequency of spills has decreased. Rather than create a time-varying rate parameter, Nakassis finds a transformation of the original production data that more closely approximates a Poisson variate when considered from the standpoint of the OCS spill history. This is a subtle but important distinction that was not discussed in Nakassis' report.

The approach taken by Nakassis is to formulate three distinct, single-parameter transformations of the original production date. Each of these transformed variate-families are then treated as candidates for a new exposure variate for modeling the spill generation process. Nakassis uses a maximum likelihood method to select an optimal value for the fitted parameter in each family, and the magnitude of the likelihood function is used to determine if one of the transformation families is a better choice than the others.

The maximum likelihood calculation is based on the distribution of the number of spills that can occur in an interval of arbitrary length of the exposure variate. At its most rudimentary form, the maximum likelihood idea can be thought of as a way of fitting annual exposure to the original spill incidence data. The probability of having no spills over a small interval is large (say close to 1.0), while the probability of having many spills is small. Each transformation proposed by Nakassis will assign its own unique pattern of large and small intervals to the original data. Inevitably, one of the transformations will do a better job of recasting the original production data in terms of the magnitude of the maximum likelihood function. If we have some years with many spills, the "best" transformation will cause these years to have large increments of exposure. In years with no spills, the "best" transformation will have small increments in exposure.

Nakassis selects his intervals to correspond to the increments of the transformed variates that occur over the calendar dates 1 January to 31 December in each of the years 1964 through 1980. (It is this procedure that results in the controversial first spill interval.) Since it is assumed that the spill generation process is Poisson, the distribution of the number of events in an interval of arbitrary length is given by the Erlang distribution, and Nakassis' likelihood function is based on this functional form. The procedure used by Nakassis to find the maximum likelihood solution exploits the properties of this likelihood function under the assumption that the transformation is linear over any given 1-year interval (Nakassis pers. comm.); this assumption is not explicitly stated in the open-file report. The procedure adopted by Nakassis is mathematically rigorous except for this assumption which oversimplifies the exposure variate behavior.

With each transformation that Nakassis postulates, the observed spill history creates a unique set of observations that consist of the number of events that occur over intervals that correspond to a calculable (and variable) exposure. This exposure is determined by the change in the transformed variate over the annual interval. The transformations proposed by Nakassis are one-parameter functions, and his optimization process is directed at finding the optimal value of this parameter for each family.

For expository purposes, it is easiest to consider a discrete version of Nakassis' problem. Imagine that we are given three different transformations with fixed parameters, and that we have calculated the increments in these exposure variables for each of the 17 years in our sample. Our data will then consist of three arrays of numbers. Each array will have 2 columns and 17 rows. In any given row, the first column will contain the number of spills observed, and the second column will contain the change in the transformed variate from 1 January to 31 December in the year corresponding to the row. For each of the transformations of the original oil production data, there will be a best estimate of the Poisson rate parameter; this estimate is simply the number of spills divided by the total exposure over the 17-year period. Given the exposure, the number of events, and the rate parameter, the Erlang distribution provides us with a probability for the outcome of each row. Assigning such a probability to each row, the arrays can then be assigned cumulative likelihoods that are the product of the row-wise probabilities. Among all three, one array will have the largest likelihood product. It will be the maximum likelihood transformation. The method employed by Nakassis simply expands the range of possible transformations to include the possibility of continuous variation in the transformation parameter.

In its general formulation, Nakassis' method is correct. But in some details, methodology is approximate and prone to error. For example, the assumption that the exposure of the transformed variate over a year can be approximated by the product of the average production rate and the value of the transformation function at the beginning of the year is not warranted in the early period of the analysis. As we show in the section below, this assumption predicts that the probability of having no spills over a year is about 0.6, whereas a more exact solution places this probability at about 0.45. Nakassis' approach leads to a simpler estimation problem but at the expense of accuracy.

There is another feature of Nakassis' analysis that bears discussion. There is no guarantee that his fitting procedure would reject a false fit to the data. The maximum likelihood method simply ensures that of the possibilities considered, the one selected has the closet fit to the pattern implied by the Erlang distribution. The maximum likelihood procedure does not distinguish between good and bad choices except to the extent that the analyst had included a sufficiently broad selection to begin with.

The only real test of the model comes from the subsequent tests of the runs and correlations of the fitted data, but the eight or nine data points have already been used to reject three parameters and to estimate two more. It is likely that the fit is only apparent.

The Model Implied by a Time-Varying Rate Parameter

The rate of OCS oil production varied greatly with time over the period 1964-1980 (Figure A-1). The functional form proposed by Nakassis (1982) for transforming production also involves large changes from one year to the next, particularly in the 1964-1968 period (Figure A-2). In this section, exact distributions are derived for a process like that prescribed by Nakassis. Three generic production histories are considered: steady production, increasing production, and decreasing production. This analysis may be used to examine the degree of error introduced by Nakassis through his assumption that the production rate was constant through the year, and that the transformation variate could be approximated with the product of the production rate and the transformation function evaluated at the beginning of the year.

Assume that we have a Poisson process that generates spills according to the quantity of oil produced. Specifically, assume that the probability of N spills in an infinitesmal exposure interval is given by the following equation:

$$P[N,\Delta q] = \begin{array}{ll} 1 - \lambda\Delta q & : N=0 \\ \lambda\Delta q & : N=1 \\ 0 & : N>1 \end{array} \qquad (1)$$

This states that the probability of observing one event is $\lambda\Delta q$, that the probability of two or more spills is identically zero, and that the probability of no spills is therefore 1 minus the probability of one spill. The exposure is denoted here by the

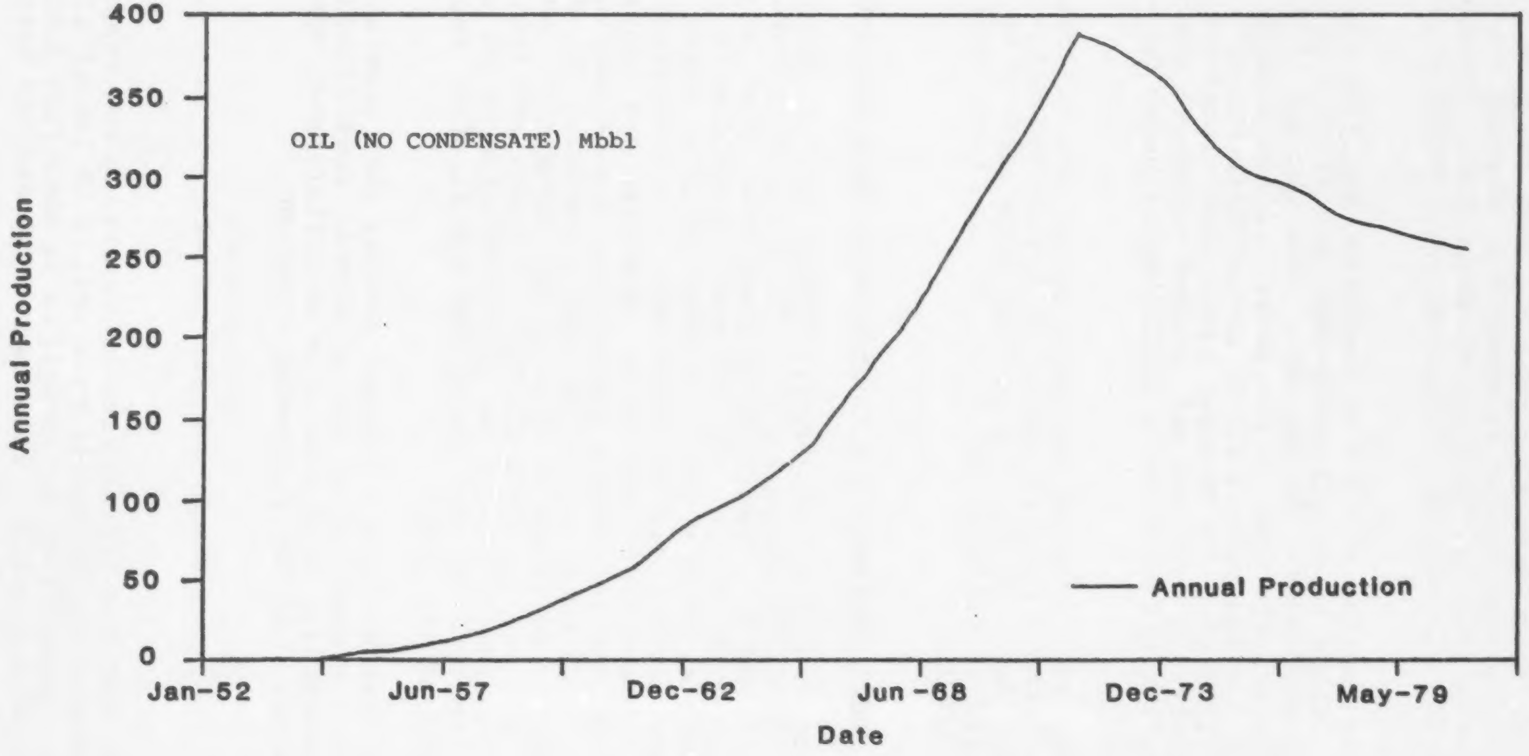


FIGURE A-1. USGS PRODUCTION DATA

SOURCE: NAKASSIS 1982; USGS 1972.

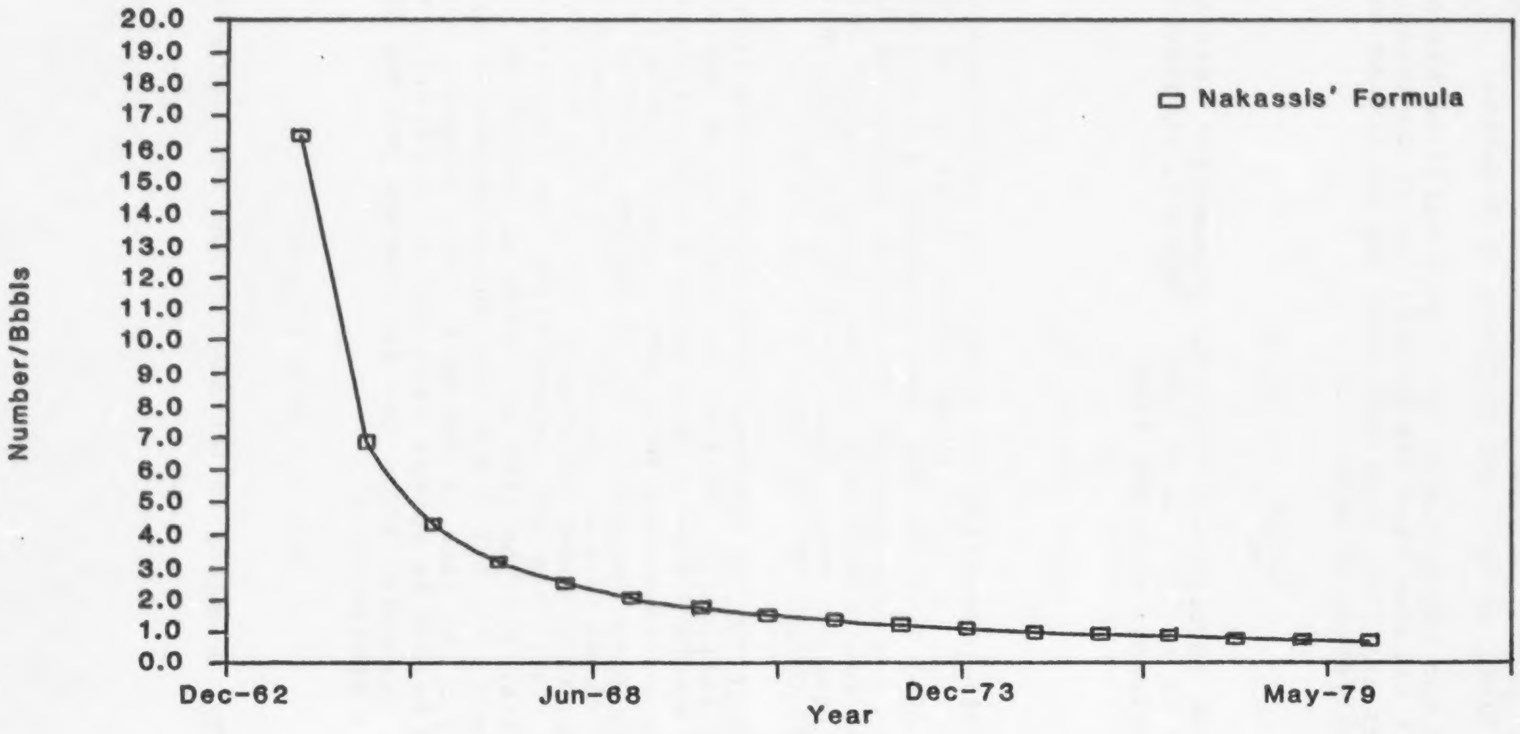


FIGURE A-2. TIME VARIATION OF THE POISSON RATE PARAMETER

SOURCE: NAKASSIS 1982.

variate "q". It is presumed to be production volume in keeping with Nakassis' paper. Assume that the spill rate constant changes with time, as is first proposed by Nakassis.

Provided the infinitesmal spill probabilities are as given above, then it follows that the probability of observing zero spills over an interval (0,q) must obey the following ordinary, first order differential equation:

$$\frac{dP[0,q]}{dq} + \lambda P[0,q] = 0 \tag{2}$$

We may now incorporate Nakassis' presumption that the rate constant " λ " is a function of time. Nakassis estimates that the best fit is obtained with the form:

$$\lambda(t) = \frac{\lambda_o}{1 + \kappa T} \tag{3}$$

But time and oil production are linked via the production history of the system that is under observation. That is, if we had one common functional form for the rate parameter but two oil fields, the field that had the greatest production during the high rate constant times would have more spills on the average (all other things being equal). More significantly, they would not share the same distribution of the inter-arrival times.

While there may be characteristic field production curves, it serves our purpose to consider the simplest of cases: a field producing at a rate R that is undergoing a linear increase/ decrease of production rate over some characteristic time. To make this idea clearer, Figure A-3 shows the inferred rates and the rate of changes of oil production rates that would be required to exactly model the annual OCS oil production data from 1952 through 1980. (In its present form, the approximation is obviously unstable. The rate of change of production rate is alternately over-estimated and then under-estimated, i.e., it oscillates from one year to the next. This suggests that 1 year is too long a period to approximate OCS oil production with the simple model presented here, but for shorter periods [e.g., 0.5 yr], it is acceptable.)

$$dq = (R + (\delta R)\times t/T_c)\ dt \tag{4}$$

and $t = T - T_o$, where T_o is the time at the beginning of the interval.

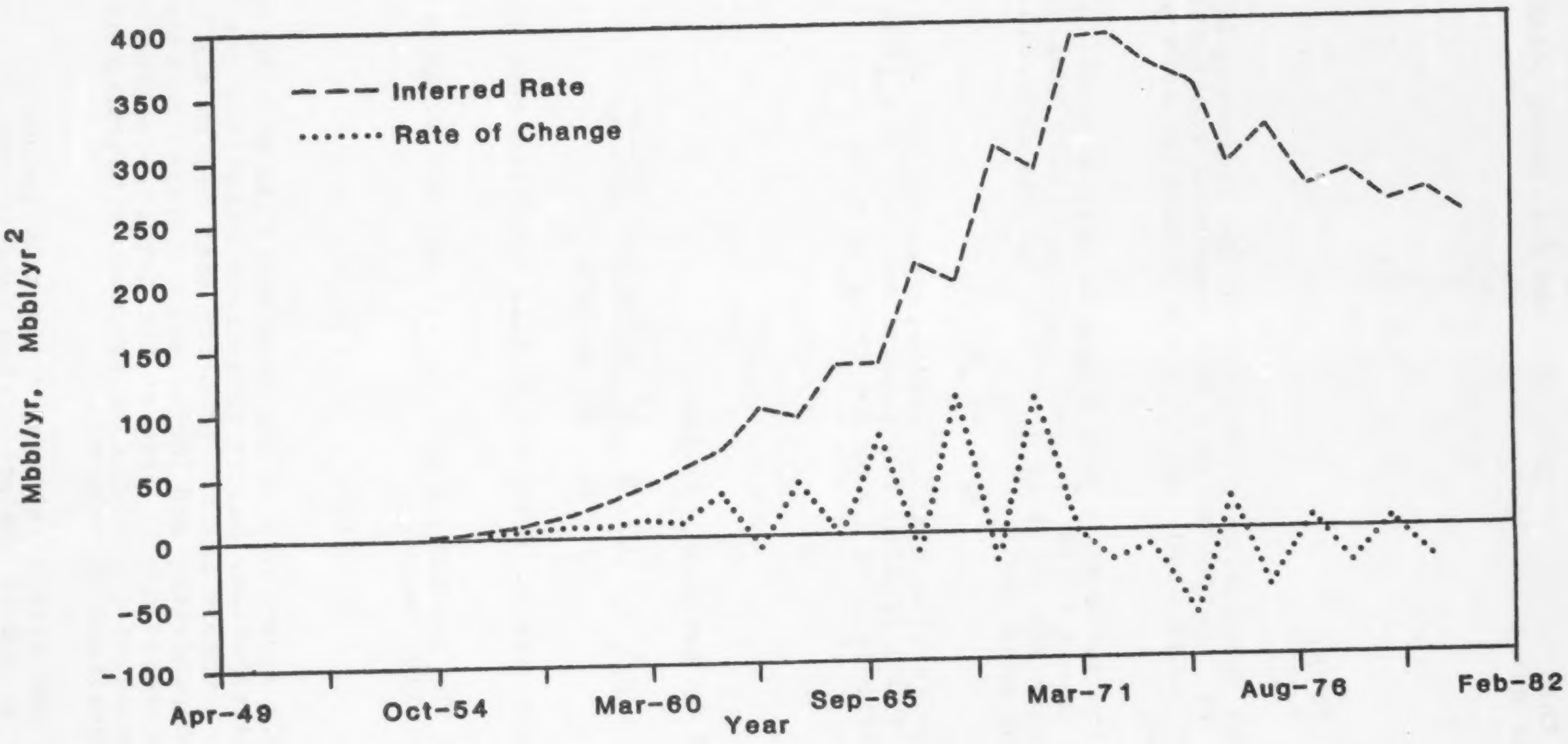


FIGURE A-3. LINEAR PRODUCTION MODEL

Given this model, we then have the following relationships between time and production:

$$q = q_o + Rt + \frac{RS}{T_c}\frac{t^2}{2} \tag{5}$$

$$t \doteq q' \left(1 - \frac{1}{2}\frac{\delta}{T_c} q'\right) \tag{6}$$

where,

$$q' = \frac{(q - q_o)}{R}$$

and q_o is the cumulative production at the beginning of the interval. The δ parameter is a nondimensional fractional value equal to the normalized change in the production rate over the time interval T_c.

Since the production rate model is only accurate over short periods, we need a suitably small characteristic time interval. A quantity with the units of time that springs naturally from parameters at hand is:

$$T_c = 1/(\lambda_o R) \tag{7}$$

This quantity is also small. Nakassis has chosen λ_o to be 16.4/Bbbls, and a typical OCS production rate is 0.25 Bbbl/yr, so the characteristic time is on the order of 0.25 yr.

Defining

$$a = 1 + kT_o \tag{8a}$$

$$b = K/R \tag{8b}$$

$$c = -\lambda_o \delta b/2 \tag{8c}$$

the solution to equation (2) is:

$$P\{o,q\} = \left[\frac{1 + (b + \sqrt{b^2 - 4ac})q/2a}{1 + (b - \sqrt{b^2 - 4ac})q/2a}\right]^{\frac{-\lambda_o}{\sqrt{b^2 - 4ac}}} \tag{9}$$

There are several features of this solution that bear discussion.

- If the production rate is steady, $c = 0$, then the solution becomes:

  $$P\{o,q\} = \left(1 + b\frac{q}{a}\right)^{\frac{-\lambda_o}{b}} \tag{10}$$

  This equation does not have the form of a Poisson distribution, but it is a close relative; and it furthermore has the property that events are independently and identically distributed when the parameter q/a is used as the exposure variate. The parameter q/a is the transformed production variate identified by Nakassis.

- If the rate of change of the rate parameter, $\lambda(t)$, is large and if the production rate is changing rapidly (the case in 1964 in the problem at hand), then the exact distribution is very different from a Poisson distribution that uses the approximation employed by Nakassis. Figure A-4 compares Nakassis' Poisson process with the exact form. Note that the exact form has a much lower probability that any given quantity of oil can be produced without incurring one or more oil spills.

- Conversely, if the rate of change parameter is small, as it is after about 1968 for the form proposed by Nakassis, then the exact solution is well approximated by the Poisson equation. Figure A-5 compares the exact solution with the Poisson solution for 1970. It can be seen that there is some difference between the two, but this is probably not significant.

Conclusions

Out of the infinitely numerous possibilities, Nakassis' "better model" is *a priori* constrained to be a Poisson process with a time dependent rate parameter and with exposure measured in oil production. Considerable ingenuity has gone into tuning this model to fit the observations as closely as possible, but the fundamental issue of the model's applicability has not been addressed. If we consider that: 1) the database consists of nine (or better yet eight) inter-arrival times for larger spills, 2) the rate parameter is estimated from the data, and 3) one of three one-parameter functional forms are also selected based on their ability to fit the observations, then it is not too surprising that the various tests do not reject the (resultant four-parameter) model.

It is important to recall the purpose of the Nakassis study. The study was undertaken to show that an hypothesis based on an improvement in OCS oil spill safety is better supported than the hypothesis that no improvement has taken place. To some degree, these problems can be addressed qualitatively without a full knowledge of the spill generation process; and based on the data, we have no quarrel with the conclusion that spills are less likely now than in 1964. But Nakassis' estimate that this increase in safety amounts to a factor of about three is dependent on the model that underlies the analysis. As we discussed above, the model has not been verified. A point of particular concern is that the spill generation process may have to do with the break-in of a new development, and the apparent improvement in OCS spill rates might really be due to the aging and maturing of the existing facilities. Under this interpretation, each new field may be subject to a pronounced "learning curve" history. In this case, we might postulate spill rates as high as those seen in the mid to late 1960s (say 5/Bbbl) for any new development. In any event, it is neither fair nor accurate to cite this paper as proof that a Poisson model driven by production volume is valid for the simulation of OCS oil spills.

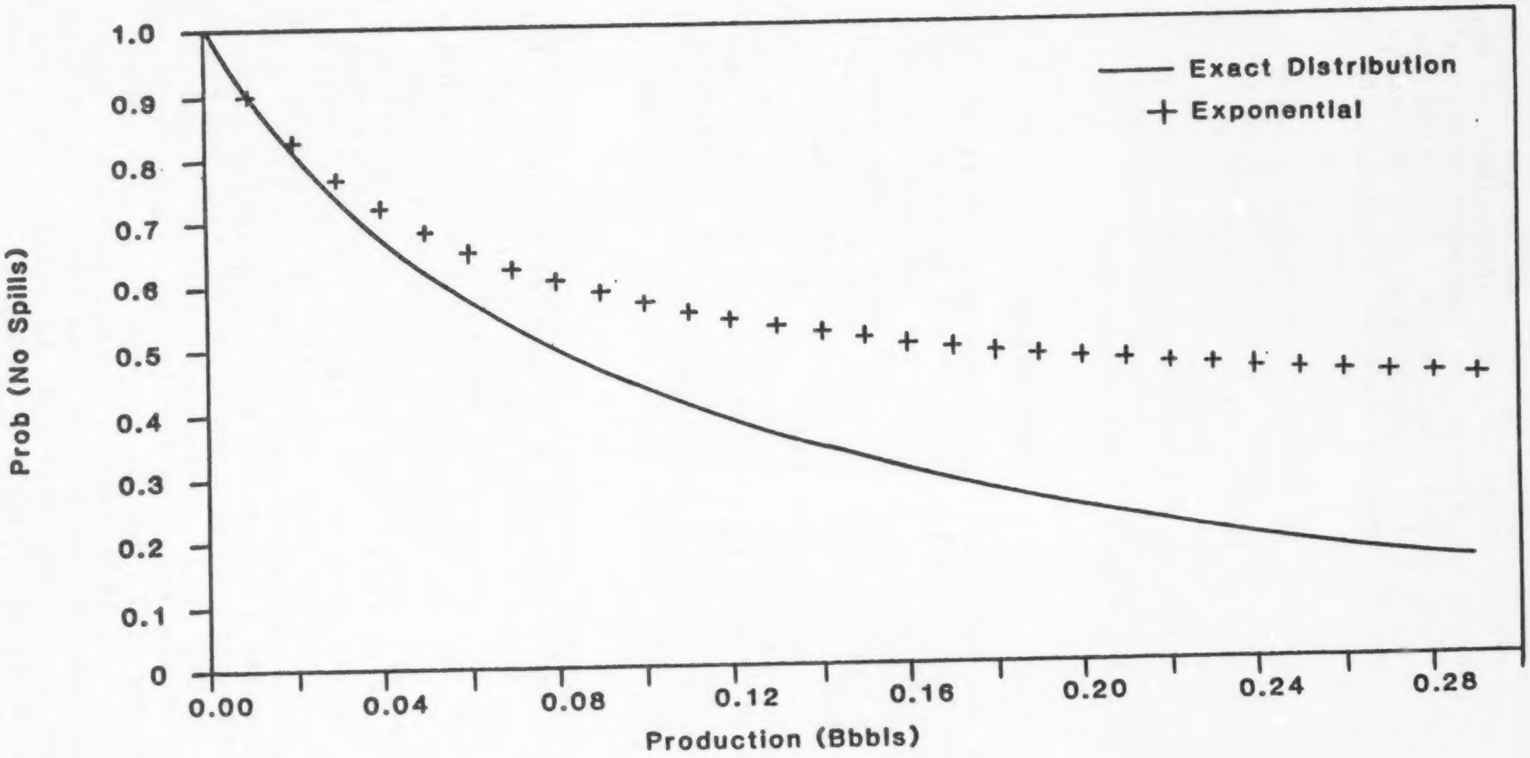


FIGURE A-4. PROBABILITY OF NO SPILLS OCCURRING, 1964 COMPARISON

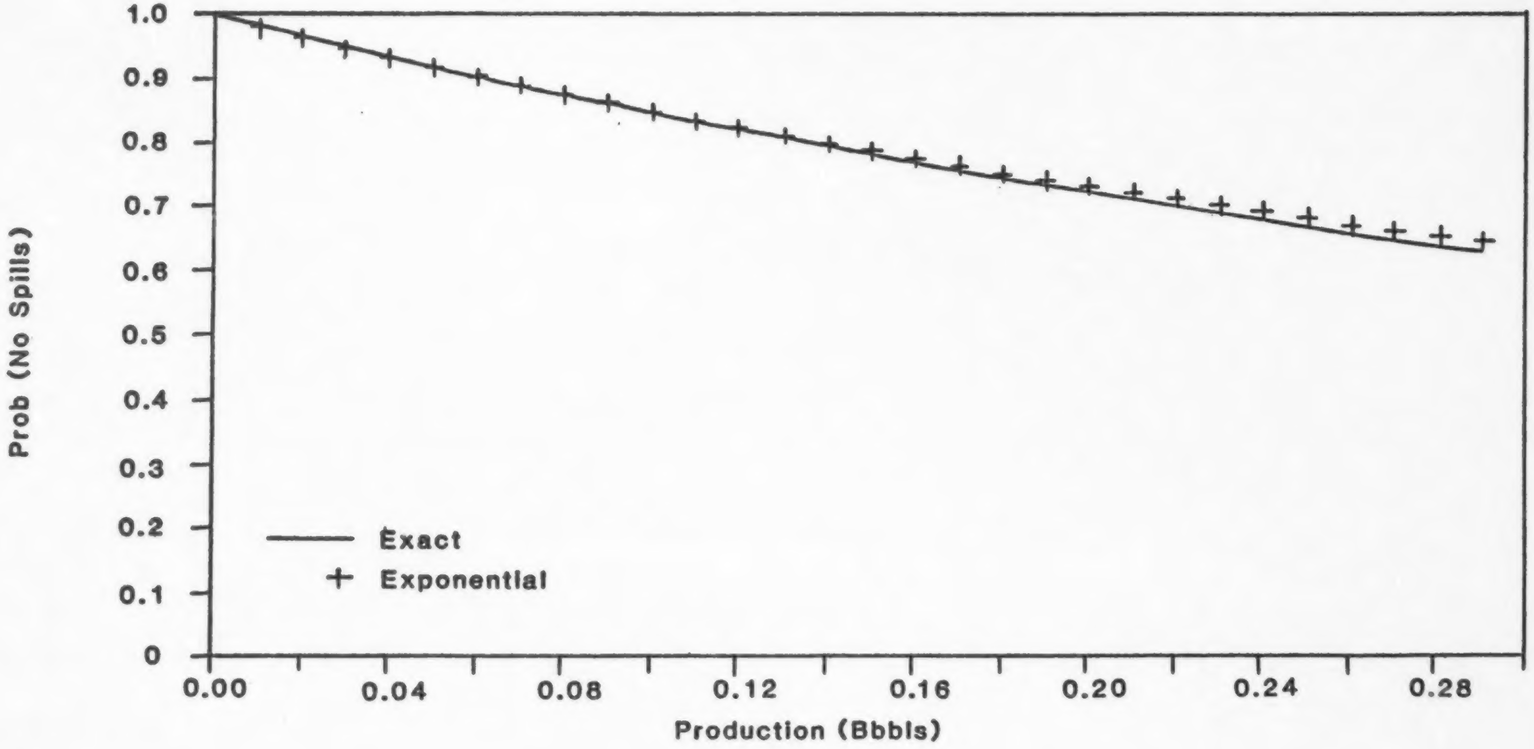


FIGURE A-5. PROBABILITY OF NO SPILLS OCCURRING, 1970 COMPARISON

Appendix B

DEPICTION OF OIL SPILL STATISTICS

Summary

This appendix contains graphical presentations of two sets of oil spill data: spill statistics for Cook Inlet, taken from the DEIS for St. George Basin (DOI 1984), and oil spill statistics for all U. S. OCS platforms, compiled by The Futures Group (1982). The purpose of this appendix is to portray oil spill statistics graphically, rather than by mathematical formulae, so the reader can visualize the spill record and associated trends.

Although the Cook Inlet observations and The Futures Group compilation are independent, they have sufficient similarities so that conclusions drawn from and supported by both data sets may be assumed to reasonably represent the risks of offshore oil production. The Cook Inlet data set includes three spills of volume >1,000 bbl. Two were tanker related and one was a pipeline spill. The data for the smaller spills include spills from all sources: platforms, pipelines, and tankers. Although The Futures Group report included pipeline, tanker, and single buoy mooring spill statistics as well as platform statistics, only platform statistics are used in this discussion. The format in which the data are presented in The Futures Group report is not convenient for combining information from different risk sources.

For this discussion, we do not restrict the initial discussion to large spills; rather, we focus on all sizes of spills. This allows a large data set to be visualized, and occurences of large spills can be interpreted within the framework of all spills.

Four of the fundamental assumptions in the MMS oil spill risk model are:

1. that spill frequency is directly proportional to production;
2. that there has been an improvement over time in the spill rate;
3. that the frequency of occurrence of oil spills can be approximated by a Poisson distribution; and

4. that the statistics describing small spills (<1,000 bbl) are different from those describing large spills because the causes of large spills are different.

If the MMS model assumptions are correct, it follows that the graphs depicting oil spill statistics would generally show the following:

- Observed spill rates that increase monotonically and linearly with increases in production.
- Improvements in spill rates.
- Ability of the Poisson distribution to estimate spill frequency.
- Differences between statistics for all spills and statistics for only large spills.

However, the graphs present the following general patterns:

- The Futures Group data, in particular, indicate a bimodal nature to spill frequencies with high spill rates at both low and high values of production. Cook Inlet data do not have as clear a bimodal nature.
- There is a relationship between spill frequencies and changes in production.
- The Poisson distribution tends to underestimate the probability of occurrence of years with few spills and also to underestimate the probability of years with many spills.
- Properties and dependencies of all spills appear to be similar to those of only larger spills.

Cook Inlet Data

Figure B-1 shows the cumulative number of spills as a function of the cumulative oil production for Cook Inlet. All spills reported and all spills of known volume >1 bbl are shown. An immediate observation from these figures is that a straight line fit to the observations would not pass through the origin. Care must be exercised in interpreting this figure since any two increasing (cumulative) functions graphed against each other will always show a trend even if they are totally unrelated. The important point established by this figure is that if there is a relation between spills and production, the relation does not predict zero spills at zero production. One interpretation of this observation is that a small number of spills will occur which is associated with any startup activity and is not

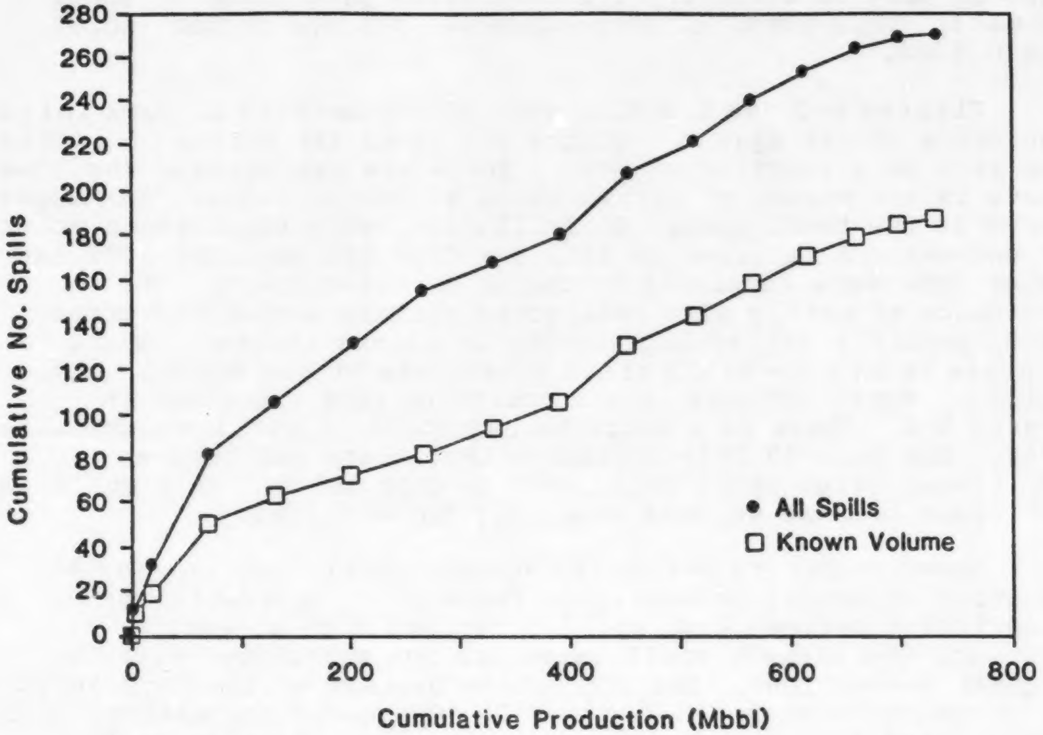


FIGURE B-1. COOK INLET: CUMULATIVE NUMBER OF SPILLS VS CUMULATIVE PRODUCTION dependent on the amount of oil produced. A second interpretation is that there has been an improvement in the spill rate, particularly early in the production period. A lessening of the spill rate diminished the slope of the curves in the figure. This is seen to occur after a cumulative production of about 80 Mbbl. This level of production was reached in Cook Inlet about 1968.

Figures B-2 and B-3 show some of the details of Cook Inlet incidence of oil spills. Figure B-2 shows the number of spills per year as a function of year. There are two curves, the lower curve is the number of spills whose volume is known. The upper curve is the total number of spills including those whose volume is unknown. Data prior to 1972 are from EPA records; 1972 and later data were furnished by the U. S. Coast Guard. The incidence of spills with unreported volumes diminished after 1972, probably reflecting changes in record keeping. There appears to be a downward trend after 1968 of the annual number of spills. Spill volumes as a function of time are shown in Figure B-3. There is a definite reduction in spill volume after 1969. The Sale 89 FEIS indicates that there has been an additional large spill since 1980 in Cook Inlet. This spill is not shown because we used data only through 1980.

Shown in Figure B-4 is the annual spill frequency as a function of annual production. There is an indication of association between high spill rates and high production. However, the highest spill rates are not associated with the highest productions. The production history of the Cook Inlet development is shown in Figure B-5. One could ask whether spills are related to large changes in production. Stable, high production occurred between 1969 and 1975; during this time, the spill rate was large but not at its peak. Figure B-6 shows the correlation of spills with changes in production. A trend of increasing number of spills with increasing rates of change in production may exist, but it appears weak with Cook Inlet data.

In Figure B-7, we show a comparison of actual spills and the Poisson distribution for spills as a cumulative function. The x-axis plots number of spills/yr (X) and the y-axis shows the cumulative percent of years with spills less than X. Two curves are shown, one for the Cook Inlet observations (271 total spills) and one for the Poisson predictor with a rate constant of 16.9 spills/yr (the observed average spill rate). The cumulative probability graph shows that for years with few spills (e.g., 10 spills or less), the Poisson distribution underestimates the cumulative frequency of occurrence. Thus, the Poisson distribution predicts that 5 percent of the years will be characterized by 10 or fewer spills, whereas Cook Inlet had 20 percent (3 of 14 years). For years with many spills (e.g., 30 spills), the Poisson distribution overestimates the cumulative frequency of occurrence; however, it overestimates the cumulative frequency of years with 30 or less spills. It follows, then, that the Poisson distribution underestimates the cumulative

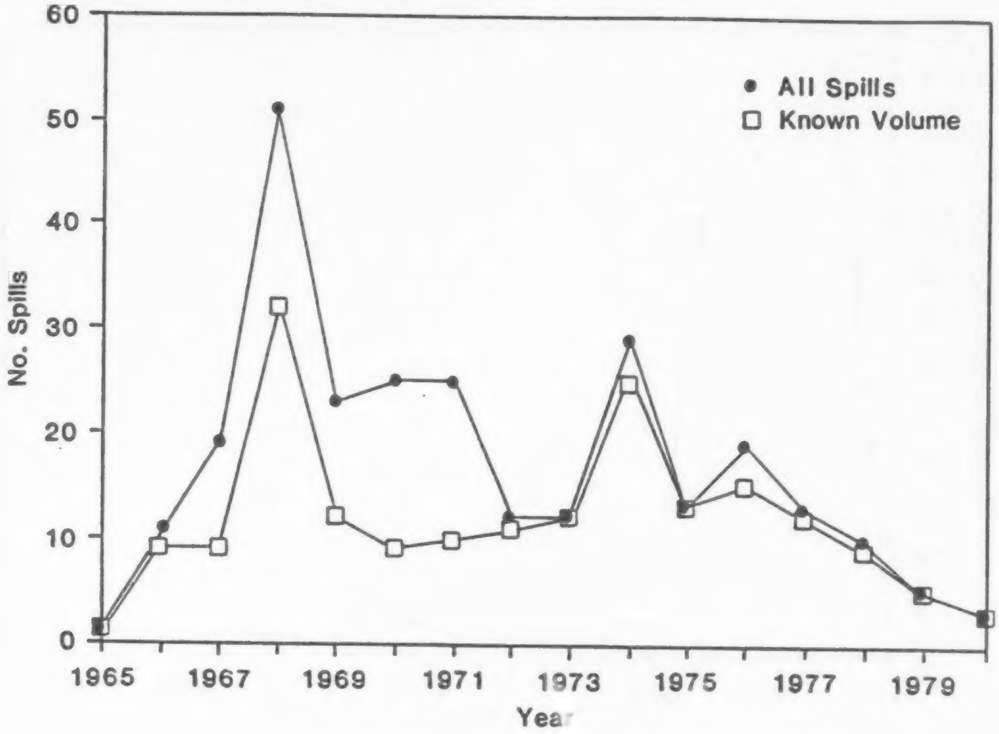


FIGURE B-2. COOK INLET: ANNUAL SPILL RATES

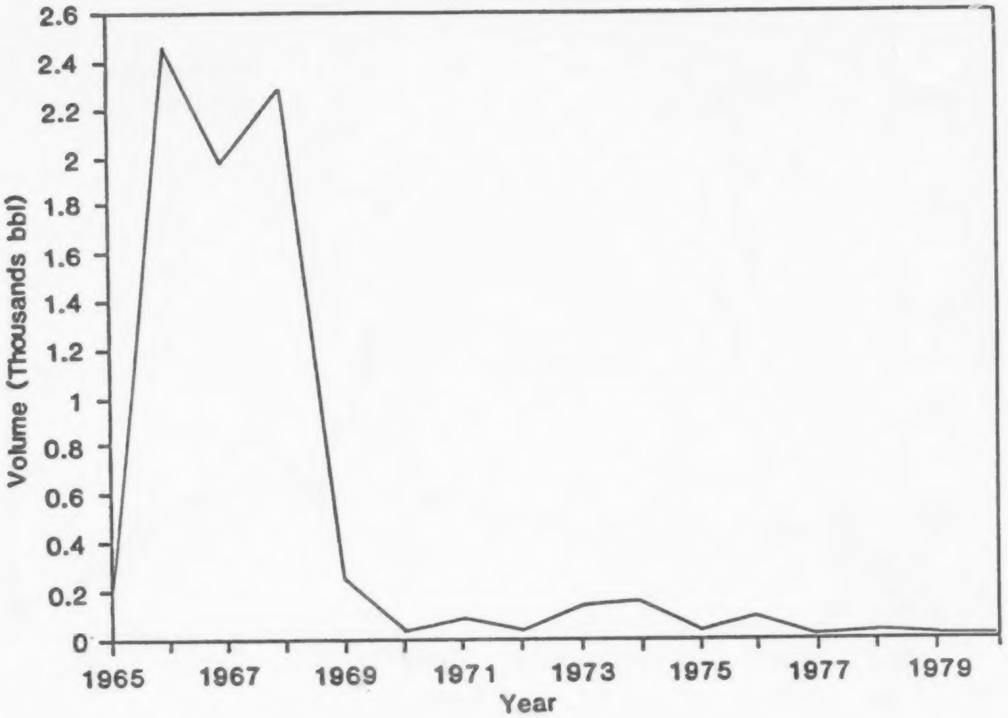


FIGURE B-3. COOK INLET: ANNUAL SPILL VOLUME

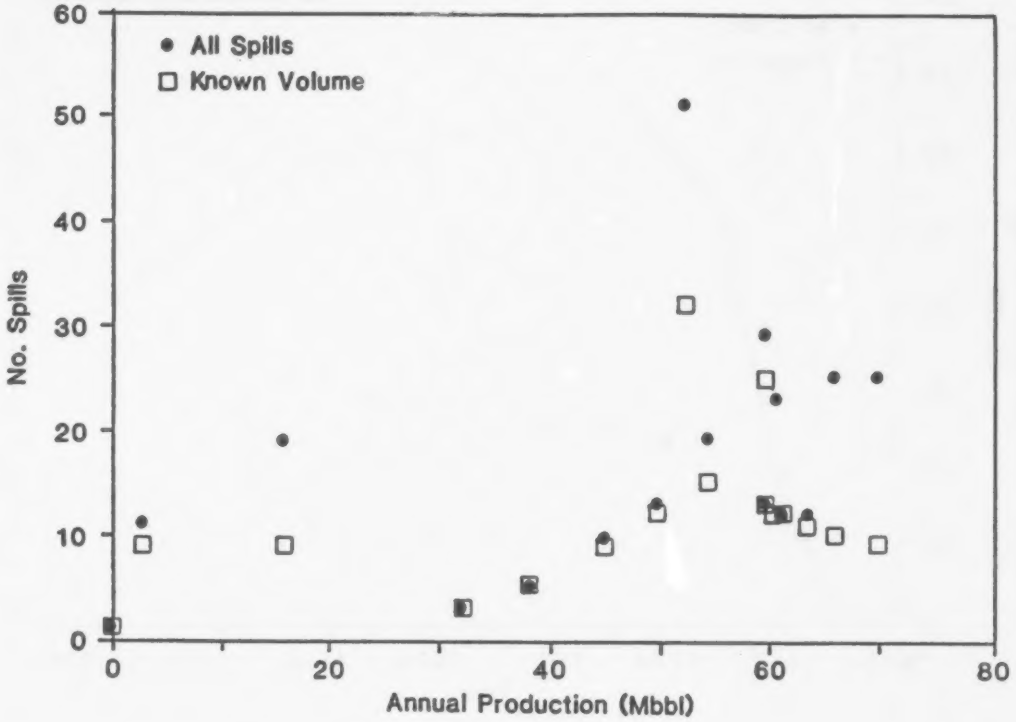


FIGURE B-4. COOK INLET: SPILL RATES VS ANNUAL PRODUCTION

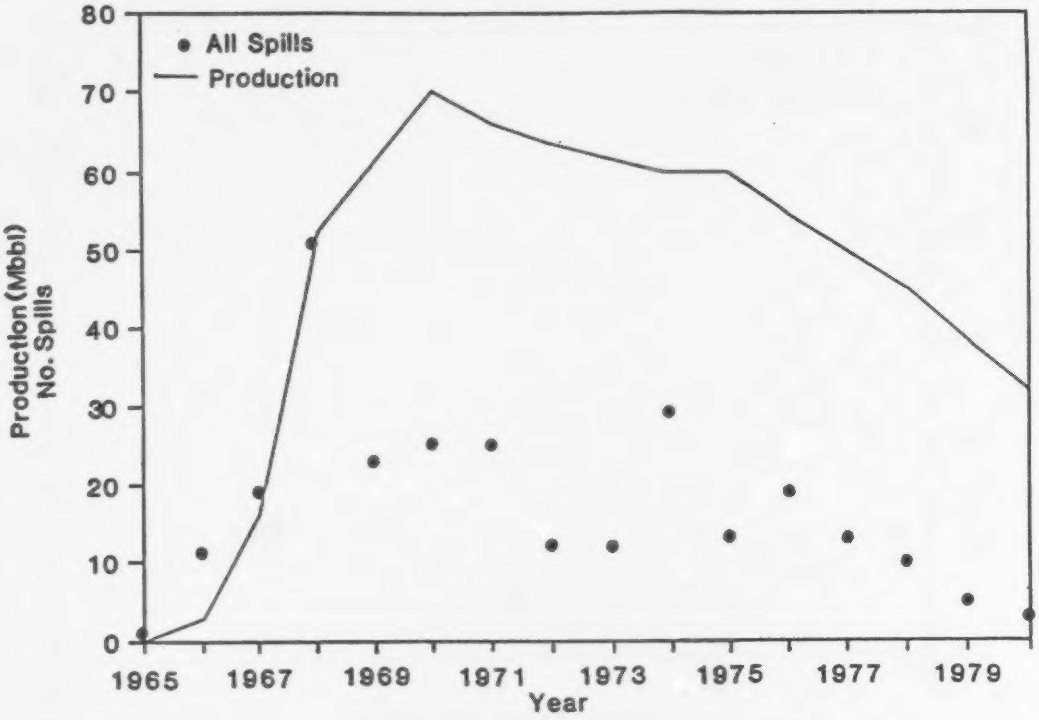


FIGURE B-5. COOK INLET: PRODUCTION AND NUMBER OF SPILLS OVER TIME

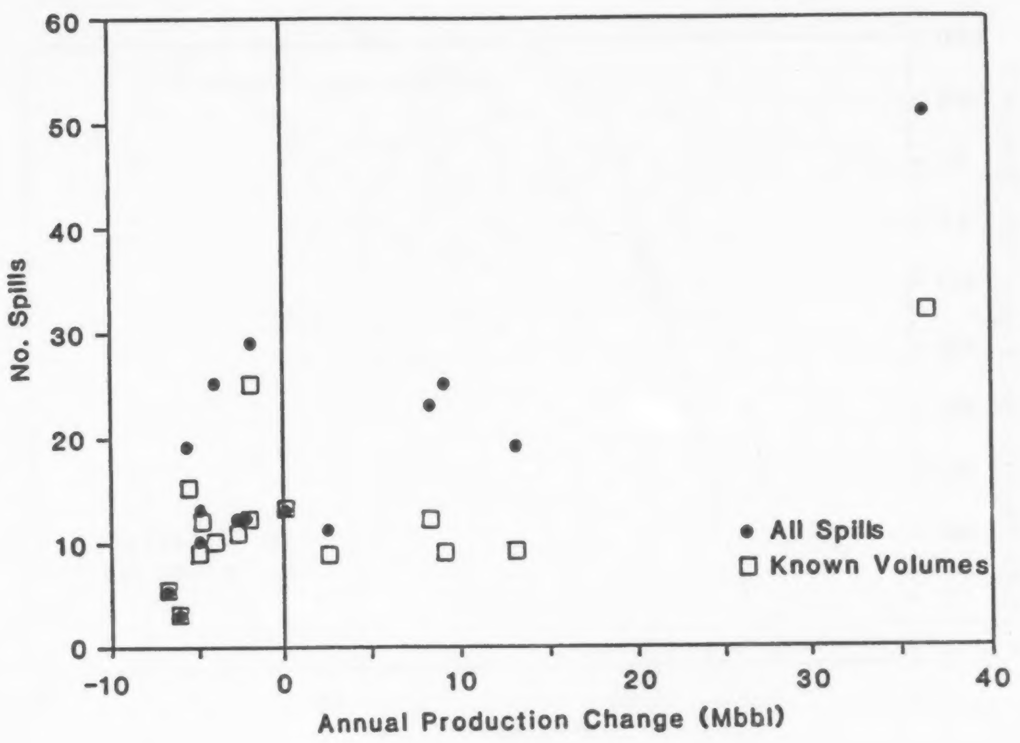
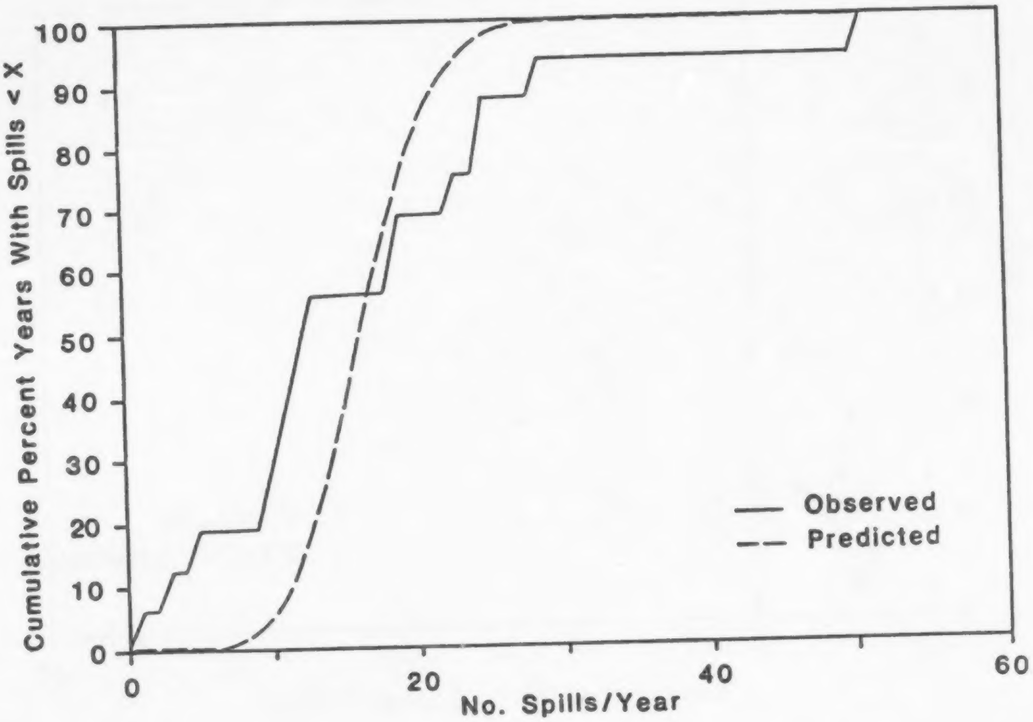


FIGURE B-6. COOK INLET: NUMBER OF SPILLS VS CHANGE IN PRODUCTION



NOTE: PREDICTED CUMULATIVE FREQUENCY DERIVED FROM POISSON DISTRIBUTION WITH EXPECTED MEAN = 16.9 SPILLS/YR.

FIGURE B-7. COOK INLET: CUMULATIVE FREQUENCY OF OBSERVED AND PREDICTED SPILL RATES frequency of years with 30 or more spills, i.e., underestimates the occurrence of years with many spills.

Thus, in reviewing Cook Inlet data, it appears that:

- There is an indication of improvement in spill statistics.
- Spill rates may depend on large changes in production rate as well as production level, but the database for Cook Inlet is relatively small and trends are not clearly observed.
- The Poisson distribution underestimates the number of years with few or many spills.

Because the Cook Inlet database is relatively small, it is important to determine whether similar observations are evident with the larger database provided by The Futures Group (1982).

The Futures Group Data

The Futures Group information includes only spills larger than 50 bbl and, furthermore, breaks the spills from platforms into three categories: blowout, tank, and other spills. We consider the sum of all platform spills independent of category.

Figure B-8 shows the cumulative number of spills as a function of cumulative oil production on the U. S. OCS. Two curves are shown: one for all spills >50 bbl and one for all spills >1,000 bbl. A similar trend was seen in Cook Inlet data (Figure B-1). Prior to the production of the first Bbbl, the curves for all spills and for spills >1,000 bbl are similar. This could be due to a number of causes, e.g., better reporting of small spills later on in production, or improvements which helped keep spills (when they occurred) to a small size.

Figure B-9 is also similar to Cook Inlet data (Figure B-3) in showing a dramatic reduction in volume spilled since the early 1970s.

Figures B-10 and B-11 display some of the details of The Futures Group platform spills. Figure B-10 shows the number of spills per year, with spills defined by five categories: >50, >100, >250, >500, and >1,000 bbl. Figure B-11 shows the production history of the production platforms considered in The Futures Group report.

Spills as a function of production are shown in Figure B-12. They show a bimodal pattern of higher spill rates at high and low production levels. The bimodal pattern is more pronounced than for Cook Inlet data (Figure B-4). Thus, it appears that production level alone is not the sole predictor of spill rates.

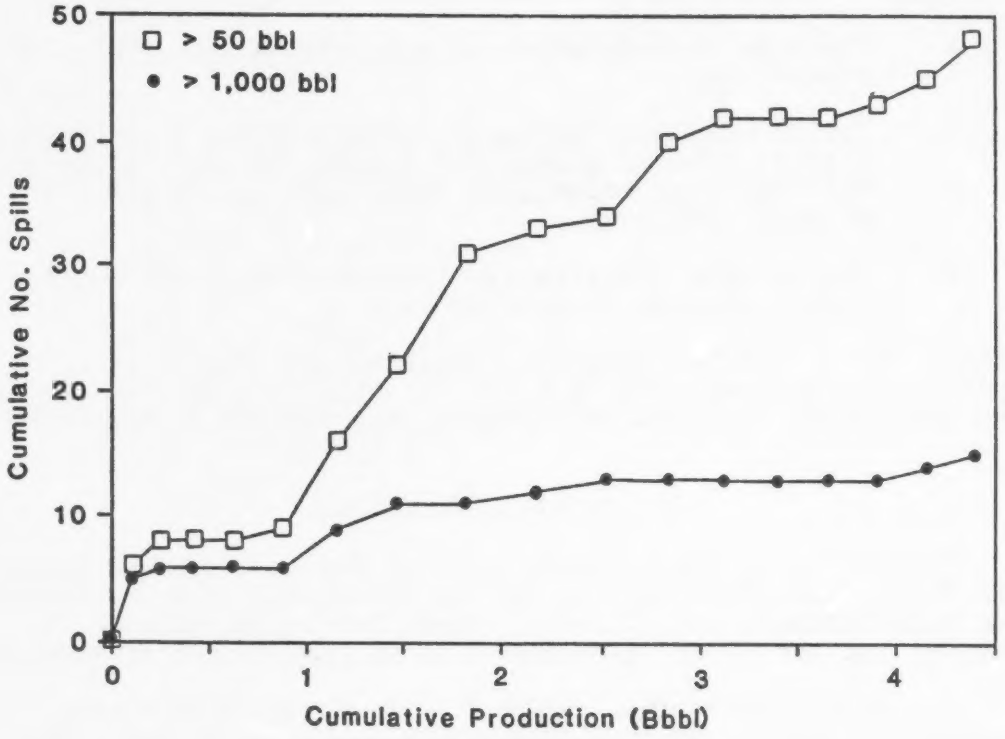


FIGURE B-8. U. S. OCS: CUMULATIVE NUMBER OF PLATFORM SPILLS VS CUMULATIVE PRODUCTION

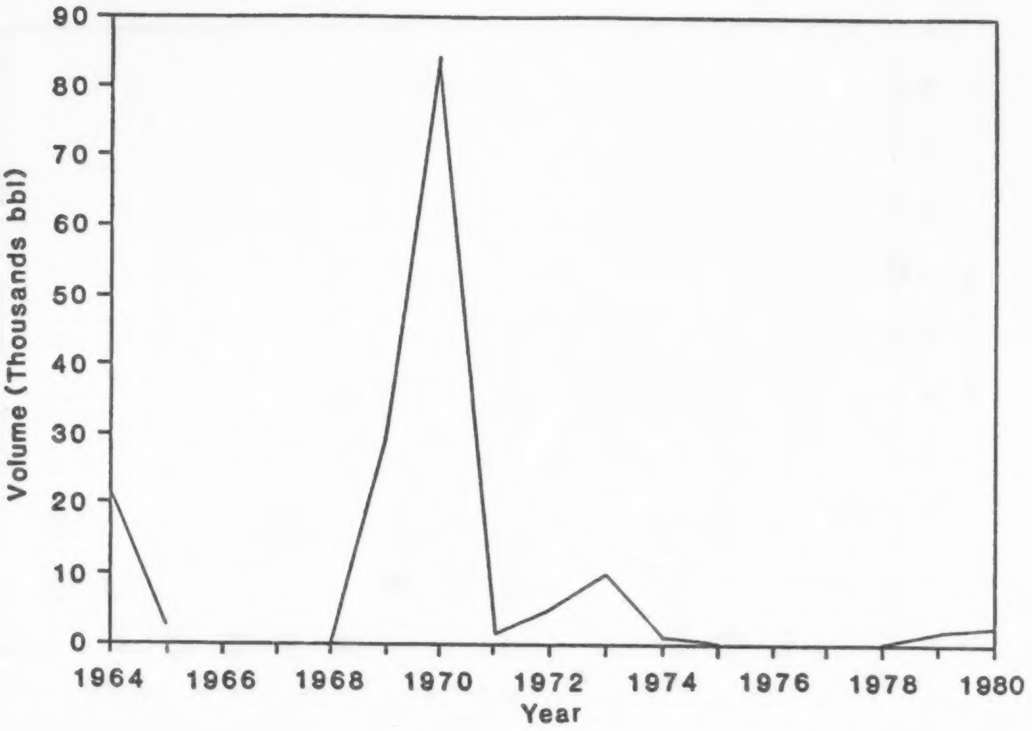


FIGURE B-9. U. S. OCS: ANNUAL PLATFORM SPILL VOLUME

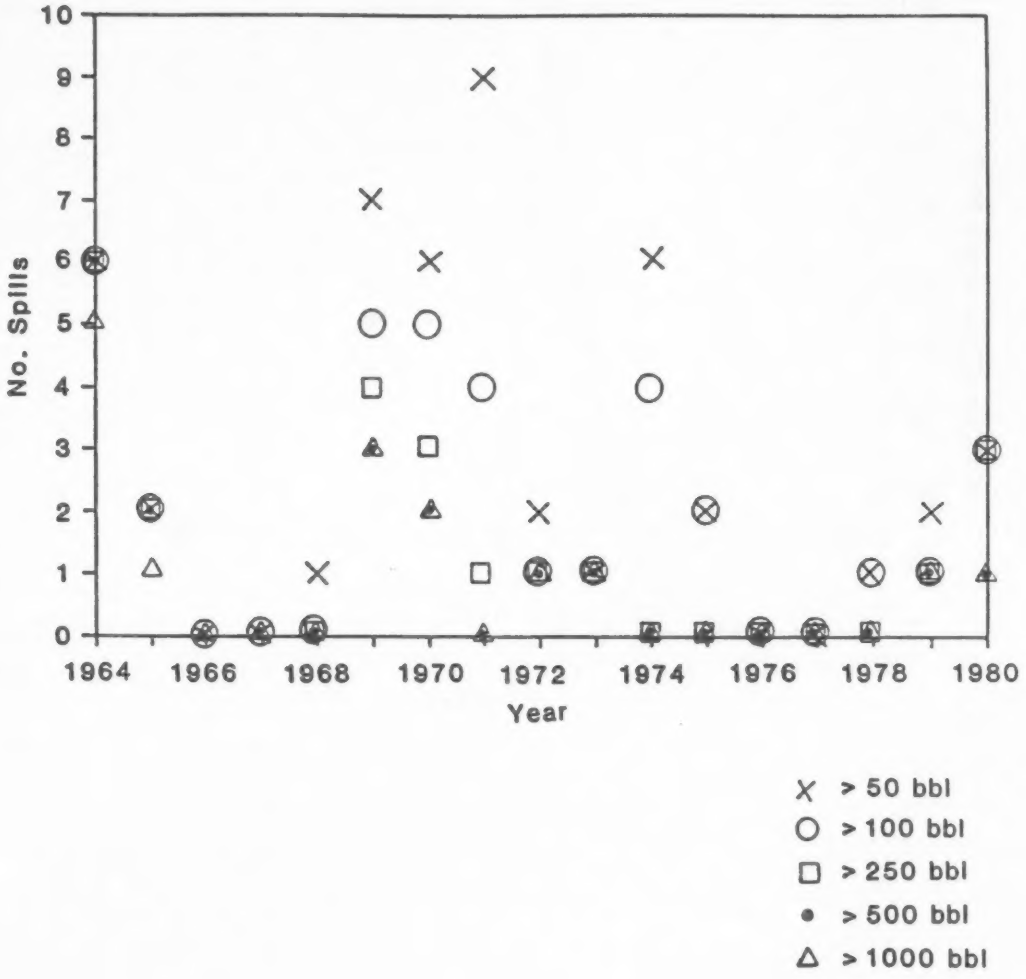


FIGURE B-10. U. S. OCS: ANNUAL PLATFORM SPILL RATES

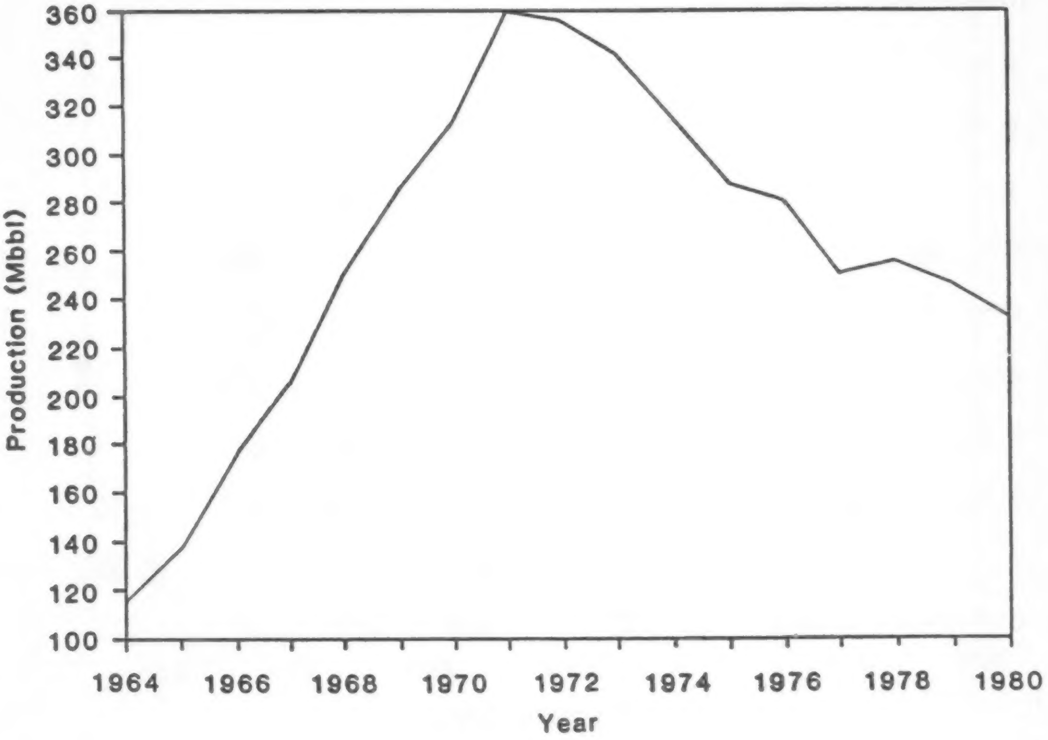


FIGURE B-11. U. S. OCS: PRODUCTION OVER TIME

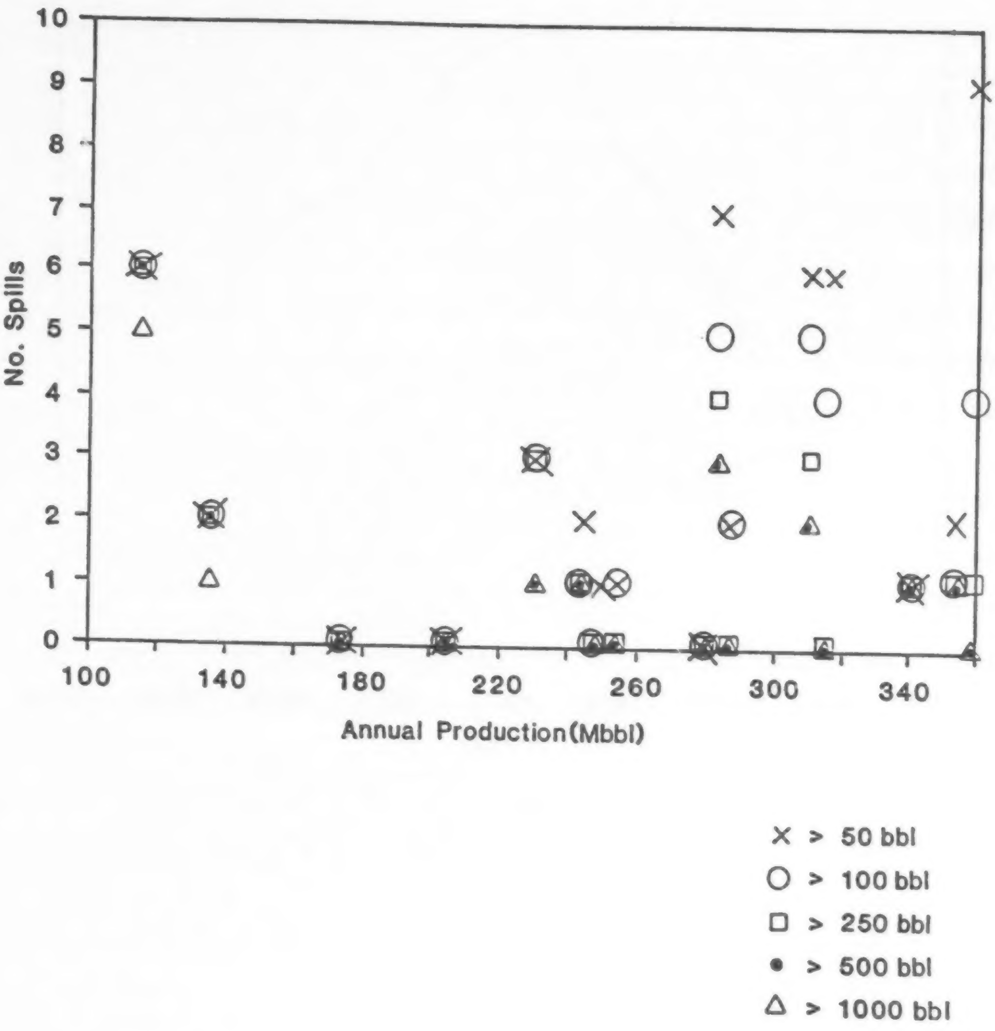


FIGURE B-12. U. S. OCS: PLATFORM SPILL RATES VS ANNUAL PRODUCTION

Figure B-13 shows spill rates as a function of change in production. In this figure, we see that spill incidence is highest for both positive and negative changes in production and least for little change in production. Figure B-14 compares spill rates with the magnitude of change in production. Although there appears to be a relationship indicating increased risk with increased change, the data would not be significantly fit with a straight line. The important point of the figure is that highest spill rates are more closely tied to the larger changes in production. If there is a year of many spills, this year is more likely to be a year of high production change than a year with production similar to the previous year.

Figures B-15 to B-19 compare spill rates with predictions from a Poisson distribution. For all categories of spill sizes, the Poisson distribution underpredicts the frequency of occurrence of years with few spills and also underpredicts the frequency of occurrence of years with many spills. The same pattern was observed in the Cook Inlet observations (Figure B-7).

The Kolmogorov-Smirnov test is a crude statistical method of examining goodness of fit of observations to predicted cumulative frequency distributions. It is a fairly simple test that has one advantage of quickly identifying data sets that do not fit predicted distributions. (Because of its nature, it is not capable of demonstrating that a set of data does fit the expected pattern.) The calculation on the data for large spills (>1,000 bbl) recorded in Figure B-19 reveals that the observations pass the test at the 85 percent confidence limit. At this level of confidence, spill rates for >500 bbl (Figure B-18) also pass the test, but spill rates for >50 bbl, >100 bbl, and >250 bbl do not pass the test. Thus, the pattern of all spills is not fit by a Poisson distribution.

MMS assumes that the causes of large spills are different from causes of small spills. For example, large spills tend to be due to blowouts or collisions (major accidents), whereas small spills tend to be caused by equipment failure or human error. On the other hand, one could argue that major accidents also can result from human error and equipment failure, and the main difference is one of magnitude. Figures B-15 through B-19 show that all size classes of spills have the same bias relative to the Poisson distribution. Figure B-7, comparing Cook Inlet spills with a Poisson model, shows the same bias. Furthermore, Figure B-10 shows that there is a high correlation between numbers of large spills and small spills per year; the correlation coefficient is 0.68. The Kolmogorov-Smirnov test results indicate that spills <500 bbl do not fit a Poisson distribution, but it is incapable of demonstrating that spills >500 bbl do fit a Poisson distribution. Nakassis (1982) also was unable to fit platform spills >1,000 bbl to a Poisson process (Appendix A). These observations suggest that the assumption that small and large spills are different must be carefully considered. It does not appear that occurrence of large spills

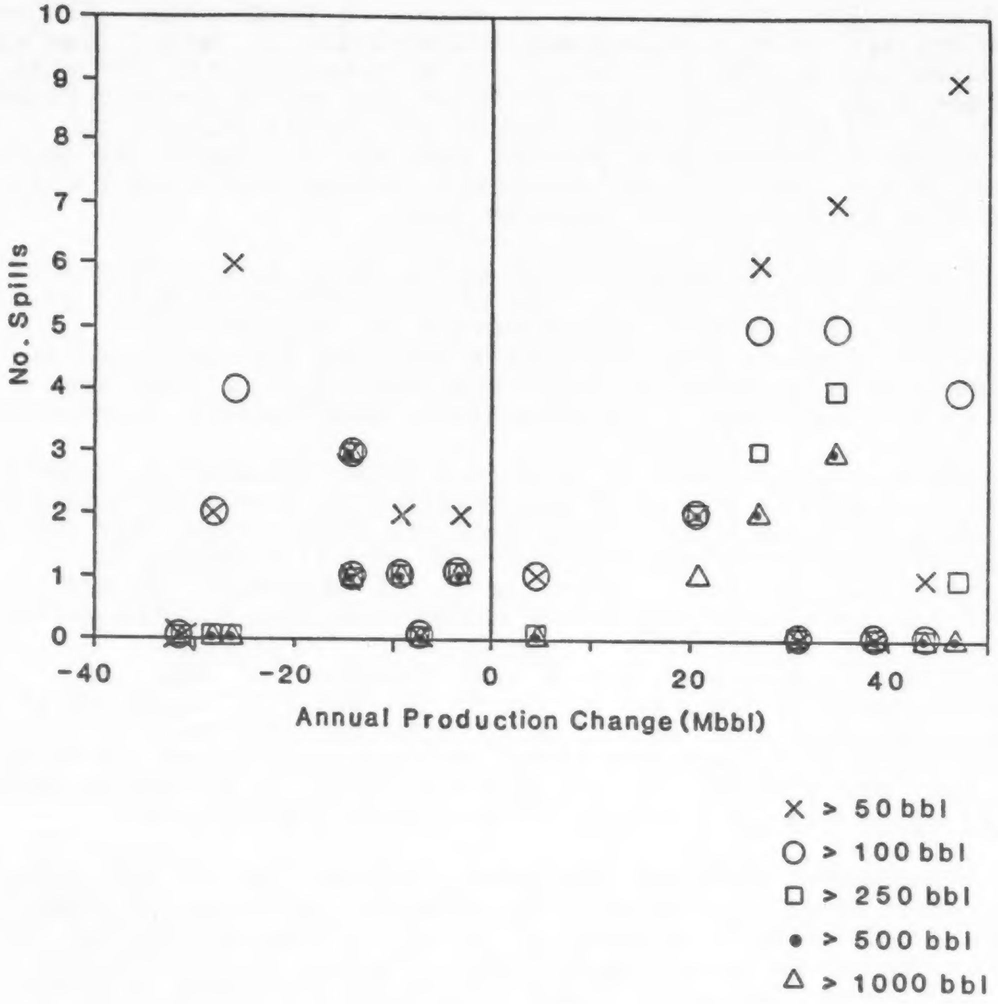


FIGURE B-13. U. S. OCS: NUMBER OF PLATFORM SPILLS VS CHANGE IN PRODUCTION

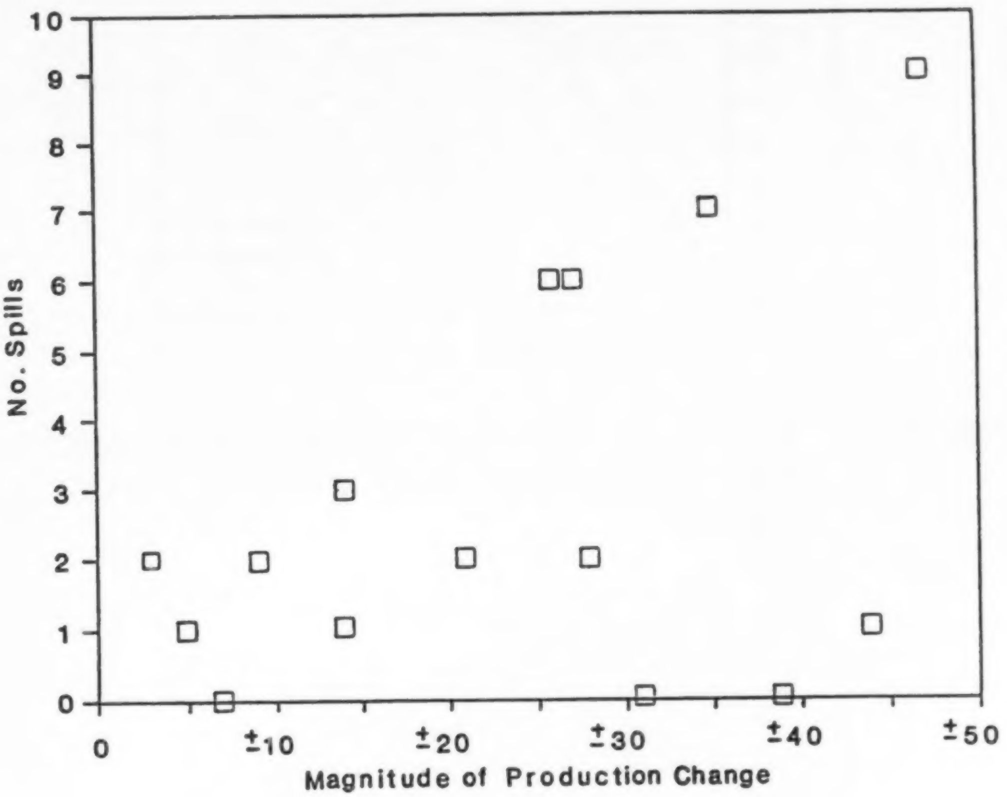


FIGURE B-14. U. S. OCS: NUMBER OF PLATFORM SPILLS >50 BBL
VS MAGNITUDE OF PRODUCTION CHANGE

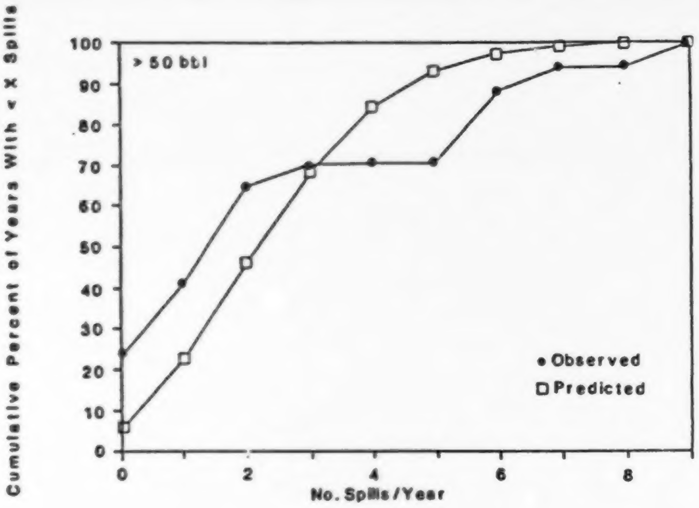


FIGURE B-15. U. S. OCS: CUMULATIVE FREQUENCY OF OBSERVED AND PREDICTED SPILL RATES (PLATFORM SPILLS >50 BBL)

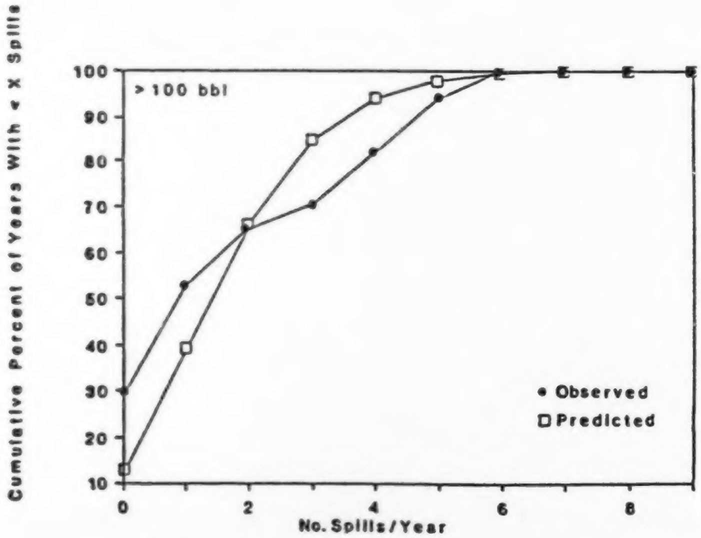


FIGURE B-16. U. S. OCS: CUMULATIVE FREQUENCY OF OBSERVED AND PREDICTED SPILL RATES (PLATFORM SPILLS >100 BBL)

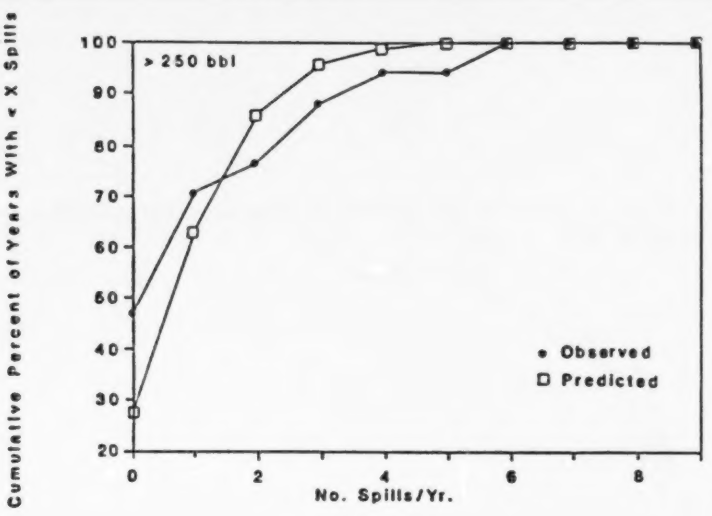


FIGURE B-17. U. S. OCS: CUMULATIVE FREQUENCY OF OBSERVED AND PREDICTED SPILL RATES (PLATFORM SPILLS >250 BBL)

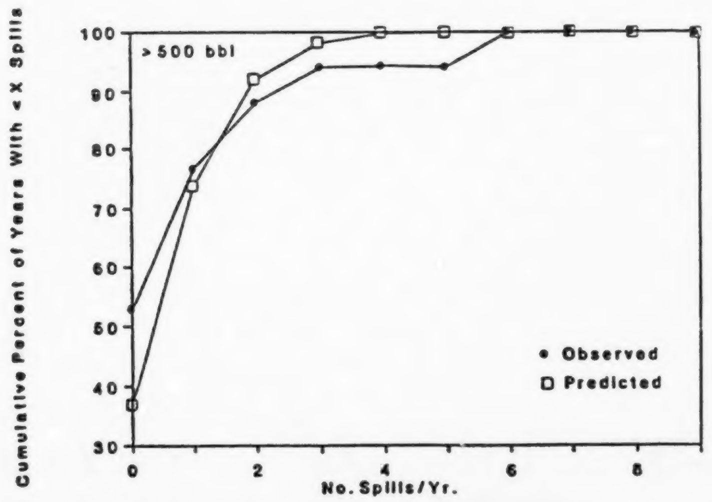


FIGURE B-18. U. S. OCS: CUMULATIVE FREQUENCY OF OBSERVED AND PREDICTED SPILL RATES (PLATFORM SPILLS >500 BBL)

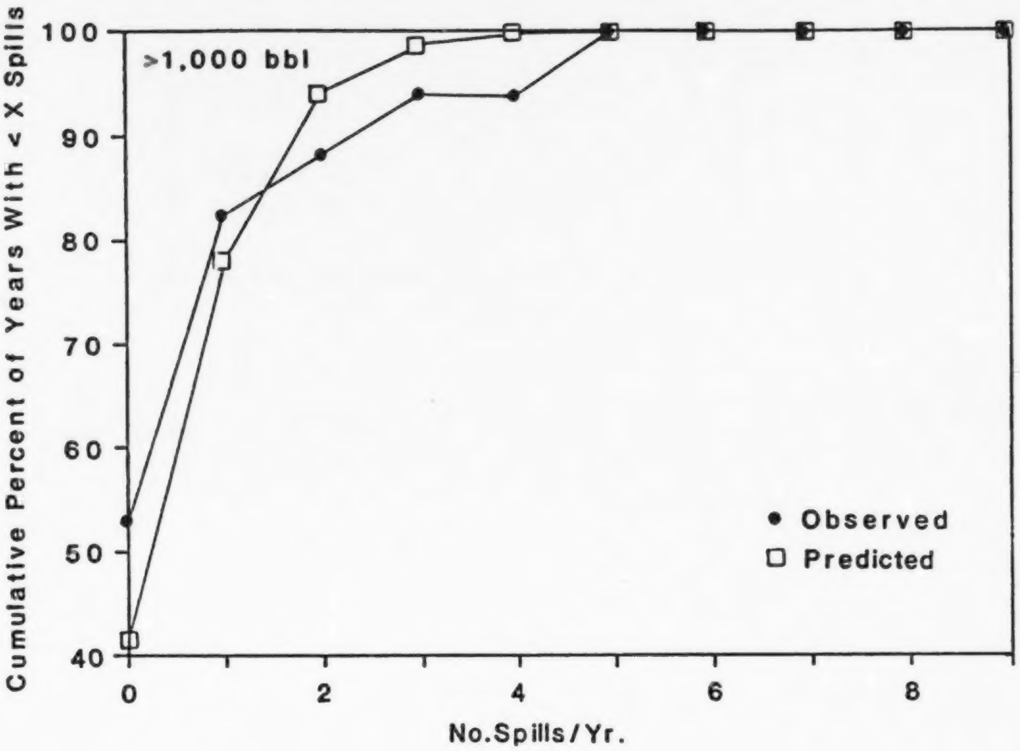


FIGURE B-19. U. S. OCS: CUMULATIVE FREQUENCY OF OBSERVED AND PREDICTED SPILL RATES (PLATFORM SPILLS >1,000 BBL) is dramatically different from occurrence of all spills (other than in magnitude).

Conclusions

Both Cook Inlet and The Futures Group data:

- Illustrate significant reductions in oil spill volumes since about 1971.
- Indicate a weak dependence of spill frequency on volume of oil produced at high volumes of production.
- Indicate a weak dependence of spill frequency on changes in oil production levels.
- Display more years of few oil spills than predicted by a Poisson distribution.
- Display more years with many oil spills than predicted by a Poisson distribution.

LIST OF PREPARERS

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